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THESIS

SERVICE LEVEL OPTIMIZATION FOR THE MARINE CORPS INSTITUTE

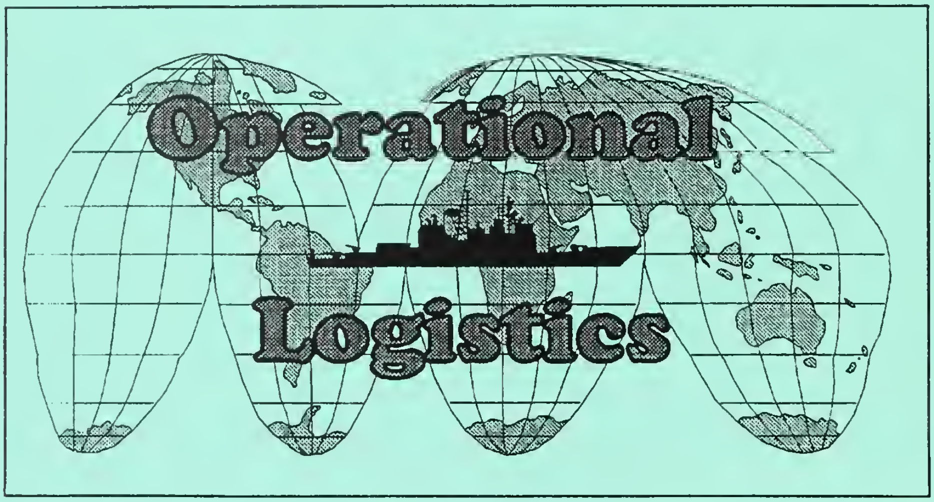
by

Gregory F. Chapman

June 2000

Thesis Advisor: Kevin J. Maher
Second Reader: David A. Schrady

Amateurs discuss strategy, Professionals study logistics



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The Marine Corps Institute (MCI) is the distance learning center for the United States Marine Corps. MCI's mission is to develop, publish, distribute, and administer distance training and education materials to enhance, support, or develop required skills and knowledge of Marines. It also satisfies other training and education requirements as identified by the Commanding General, Marine Corps Combat Development Command.

To meet this mission MCI develops and assembles course materials ranging from simple training courses to college level Professional Military Education (PME) programs. Each course or program consists of multiple components that must be printed, stocked, and distributed to all Marines. Currently MCI offers 151 courses comprised of 305 printed components. In 1999 MCI processed over 550,000 requests for course materials.

In late 1998 MCI recognized the need to improve their inventory control processes. They desired a means of determining reorder points and reorder quantities for the Marine Corps Institute in order to improve service to Marines in the field. This thesis develops a non-linear program inventory model that minimizes the number of shortages per year, and returns reorder points and reorder quantities, thereby improving MCI's service to the Marine Corps.

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SERVICE LEVEL OPTIMIZATION FOR THE MARINE CORPS INSTITUTE

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requirements for the degree of

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THESIS DISCLAIMER

The reader is cautioned that the computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the program is free of computational and logic errors, it cannot be considered validated. Any application of this program without additional verification is at the risk of the user.

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LIST OF ACRONYMS

DAPS	Defense Automated Printing Service
DoD	Department of Defense
EOQ	Economic Order Quantity
GPO	Government Printing Office
FY	Fiscal Year (1 Oct – 30 Sep)
MCI	Marine Corps Institute (also slang for course materials used in the fleet)
MCCDC	Marine Corps Combat Development Command
MBW	Marine Corps Barracks, Washington, DC
MOS	Military Occupational Specialty
NIMA	National Imagery and Mapping Agency
NLP	Non-Linear Program
NPS	Naval Postgraduate School
OPTAR	Operating Budget
PME	Professional Military Education

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EXECUTIVE SUMMARY

The Marine Corps Institute is the distance learning center for the United States Marine Corps. MCI's mission is to develop, publish, distribute, and administer distance training and education materials to enhance, support, or develop required skills and knowledge of Marines. It also satisfies other training and education requirements as identified by the Commanding General, Marine Corps Combat Development Command.

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MCI spent $1.375 million on component print costs in 1999, using most of the 40,000 ft^3 of available storage with an unknown service level. An evaluation of MCI's current inventory policy revealed that strict adherence to this policy would have yielded an estimated 5000 component shortages, utilizing 10,000ft^3 of warehouse space and $905K of OPTAR. The results of the optimization model minimizing shortages

establishes the expected number of shortages to be 33 units per year with a required budget of $790,000 and storage requirements of 16,750 ft^3.

MCI can improve upon its projected service level to the Marine Corps while decreasing its printing budget and reallocating excess warehouse space to the processing area for course storage. Adopting this inventory policy will improve upon their current performance by saving over $575,000 in printing cost, allow course storage, in anticipation of demand, and improve service by 99.3 percent.

ACKNOWLEDGEMENTS

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Special recognition is given to all at MCI who aided in the collection of data for this project and all of who patiently answered my questions and redirected me numerous times back on track. I would specifically like to thank: Dave Robnett for providing the demand data and for his help on the Print Cost Calculator, Cpl. Murray, LCpl. Gerding, and PFC Hunter for their contributions to my understanding of how print costs are determined and for their help in collecting the component characteristics, Maj. Ackley and MSgt. Shockey for enduring repeated questions and requests for data, who cheerfully and promptly provided the answers I needed.

I also need to thank Dr. Gerald Brown for his time in helping me trouble shoot the model and for his insistence that I apply what he taught to this project. Dr. Alexandra Newman who endured uncounted interruptions in her workday to aid my understanding of non-linear programming and also as a sanity check for the algorithms presented. Dr. Jayachandran who directed and checked the proof of convexity.

Special heartfelt thanks to my wife and son who endured the many complaints, late hours and exasperation with love, support and understanding.

I. INTRODUCTION

A. WHAT IS THE MARINE CORPS INSTITUTE

The Marine Corps Institute (MCI) is the distance learning center for the Marine Corps. Distance learning plays a large role in the continuing professional education of Marines. MCI fills this function by providing textbooks, handbooks, job aids, and examination packages to the Marine Corps. Many of the courses offered by MCI are designed to increase the skills, knowledge, and promotion opportunities for Marines. These course materials are available to all active and reserve Marines and play a key role in increasing the professional knowledge of all Marines.

B. BACKGROUND

The Marine Corps Institute's mission is to develop, publish, distribute, and administer distance training and education materials to enhance, support, or develop required skills and knowledge of Marines. It also satisfies other training and education requirements as identified by the Commanding General, Marine Corps Combat Development Command (MCCDC). (Table of Organization, p. 1)

To meet this mission MCI develops and assembles course materials ranging from simple training courses to college level Professional Military Education (PME) programs. Each *course* or *program* consists of multiple *components* that must be printed, stocked,

assembled, and distributed to all Marines. Currently MCI offers 151 courses comprised of 305 printed components.

The MCI Logistics Department is responsible for the acquisition, stocking, assembly and distribution of all printed course materials. It administers the printing contracts for the acquisition of components; it manages the warehouse for storing components and assembling courses; and it uses an integrated postal system to distribute the courses to their customers. The operations of the Logistics Department are discussed in depth below.

C. PROBLEM DEFINITION

1. MCI Research Request

Contact between MCI and Naval Postgraduate School (NPS) began in late 1998. MCI's Operations Officer, Maj. Guzik, drafted a statement of an inventory problem, which was displayed by the NPS Operations Department Thesis Tour Topics web page. (NPS OR website) In the outline Maj. Guzik stated that "...MCI needs a method for determining when and how many of each component to print, or order. Our goal is to minimize the time a student must wait because the requested course is not in stock." (NPS OR website) Maj. Guzik also stated that MCI had a limited printing budget and limited warehouse space for procuring and storing components. Subsequent conversations with Maj. Ackley, the current Operations Officer, and Capt. Allen, the Logistics Officer, further defined MCI's goal of establishing an inventory policy that minimizes the yearly number of component stock-outs. (Allen)

2. Why Paper Copies are Required

MCI will continue to require printed *courseware* well into the future despite the advances being made in the area of web-based and electronic education. This is because Marines will not always have access to a computer. The MCI courses are very important to Marines because they either serve as an educational aid for advancement or as an advancement requirement. (Ackley)

3. Recent Press Coverage of MCI Performance

MCI's concerns were raised publicly after a recent editorial exposed problems with their inventory system. "Marine Corps Institute Runs Like A Business – A Bad One," is the title of the editorial in the Marine Corps Times. The article gives one Marine's account of how MCI failed to properly send him courses and how MCI failed to credit his record after he completed those courses. With the emphasis that is placed on completing MCI courses and the extra points provided for advancement scores, it is understandable why the author was upset about MCI's failure to ensure his service record was updated to reflect completion of these courses. The author also makes reference to several other Marines who have had similar problems with receiving the proper education points in their service records and some who have had trouble getting the course materials that they ordered. (*Marine Corps Times*, Oct 11, 1999)

Col. G.K. Brickhouse, Director, MCI, responded to this article with a letter to the Marine Corps Times (Nov 1, 1999). In his response Col. Brickhouse admits that MCI

"…does not claim perfection, but we pursue it." He further states that MCI deals with large numbers of course requests, resulting in associated questions and service record concerns affecting each Marine enrolled in an MCI course. In fiscal year (FY) 1998 alone, MCI received approximately 485,000 course enrollments. In FY 1999 that number increased to 556.000. With such large numbers not every customer can be satisfied; mistakes are made, although "zero-mistakes" is the goal. Col. Brickhouse admits to major inefficiencies and seeks NPS help to improve service. In several conversations with the author Col. Brickhouse stated that he wants NPS to develop reorder quantities and reorder points to minimize stock-outs while operating within the print budget and warehouse capacity. (Brickhouse)

D. SOLUTION APPROACH

The problem as stated by MCI has an objective of minimizing processing time to fill requests, subject to warehouse capacity and budget constraints. MCI personnel want to fill course and program requests as quickly as possible. (Ackley) One way to reduce customer wait time is to ensure an adequate inventory of components and packaged courses. Another way of stating MCI's objective is to minimize the number of requests that can not be filled from available inventory (these unfilled requests are referred to as the *hold-file*), or to maximize the percentage of requests that can be filled immediately from existing stock.

Following this path it is possible to satisfy MCI's goal by adapting stochastic inventory service level models. Solving this problem requires using a multi-item

inventory model. The model used in this thesis is an adaptation of Schrady and Choe's "Multi-Item Continuous Review Inventory Policies Subject to Constraints" using an inventory service level model (Tersine, Chap. 5 and Winston, Chap. 16) with an objective function of minimizing stock-outs by establishing component specific reorder quantities and safety stock levels, with budget, order size, and warehouse constraints. A non-linear program (NLP) is developed to determine reorder points and reorder quantities for each component MCI uses.

Data is gathered and manipulated using Excel to determine mean monthly demand and standard deviation for each component. A Visual Basic program is developed to capture cost data for each component. A regression model is used to determine the thickness of a component, which factors into calculating the volume.

Chapter II discusses MCI's inventory control procedures and current processes. It gives an estimate of expected performance. Chapter III discusses the development of the NLP model. Chapter IV describes the results and offers a simple heuristic, which can be programmed into MCI's inventory management information system. Chapter V offers conclusions and recommendations.

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II. MCI CURRENT OPERATIONS

A. MCI INVENTORY CONTROL PROCEDURES

1. Printing Methods

MCI has four different methods of printing components, each having different costs and production time. The primary method is known as *regular print*. This process is established through a contract with a commercial printer who receives a purchase order from MCI and produces the *print job* within 10 – 15 days. The Defense Automated Printing Service (DAPS) administers this contract, which was held by Braceland Brothers, Philadelphia, PA, in 1999.

The second method is known as *print on demand*. This method allows MCI to submit to the contractor an expeditious order where the print job is produced within 5 days of receiving the order. The disadvantage of this method is its higher cost. Print jobs in this category are also managed by DAPS and produced by the commercial contractor who holds the regular print contract.

A third method of printing is known as a *one-time contract*. The one-time contract is used for the few components with complex design and multiple colors and fold-ins. When one of these components is required DAPS advertises the order for bid. The resulting contract is separate from the regular print contract and may be awarded to a different printer. DAPS manages the one-time contracts ensuring the 10–15 day production time is met. The benefit of the one-time contract is that it is less expensive for the complex components than the regular print contract.

The fourth print method is known as *in-house* printing. MCI has a printer and therefore has the capability to produce some of the components. This method is reserved for small jobs or slow moving components.

2. Internal Stock Control

Inventory control at MCI is characterized as an ad hoc process. (Ackley) MCI generates a purchase order for a print job when the stock level of a component falls between two and three month's worth of demand. The reason for such a long lead-time is the number of procedures that have to be executed in addition to the 15 days of actual printing. These procedures include pre-print review, pagination, purchase order generation, DAPS administration, and post-print review.

Pre-print review is done by the editing department to ensure that the sample being sent to the printer is the most current version, that it is error free, and that the negatives provided are in good condition. Pre-print review takes approximately five days. The Logistics department printing shop paginates the component, where the negatives are labeled with their associated "folio" number (consecutive ordering of pages from front cover to back cover). Pagination also takes approximately five days. Print requests are then written, reviewed, and signed by the Logistics Officer, incurring another three-day delay. Once the purchase order requirements have been completed, the purchase order is delivered to DAPS where more processing and delays occur before the request is submitted to the printer.

Because MCI works through DAPS, rather than directly with the printer, the total elapsed time between submitting the purchase order to DAPS and the product reception

from the printer is known as printer processing time. Under the current regular print contract DAPS has 20 days from the date they receive a purchase order to get the product delivered to MCI.

The final step is post-print review. In this step the editing department conducts quality assurance inspection. Post-print involves the inspection of a random sample of the delivered products and a thorough page check to ensure product quality. Post-print review takes an additional three to five working days.

The total delay is about 40 to 45 working days, or approximately two months, from reorder identification to product delivery. Reducing the procurement lead-time will reduce reorder points, which has a favorable affect on the total inventory system in that it will reduce the average on-hand inventory. MCI is investigating ways to decrease the print request processing time. MCI's goal is to reduce internal print request processing time from 20 days to about 12 days. One way they intend to do this is to make digital files of every component, which will help streamline pre-print review and pagination. Another avenue for decreasing order lead-time would be an investigation into whether DAPS could decrease their processing delays. MCI does not have historical data available on order lead-time. Without this data it is impossible to determine a lead-time distribution; a constant two-month lead-time is assumed. The order quantity is usually four to six months worth of anticipated demand, depending on the whims of the buyer.

Overall MCI's judgement and inventory policies would be reasonably sound if demand and lead-time are deterministic. With probabilistic demand and lead-time MCI's current policies fail to explicitly account for the variation in lead-time demand. The result is that the system does not minimize inventory costs. Using reorder points, and

thus safety stock levels, set as a function of average time supply (i.e. 3 months remaining supply) should be avoided. The fallacy in using a fixed time supply is that safety stock becomes a function of the level of demand, rather than a function of the variability of demand. (Tersine, pp. 241-2) Failing to take variability into account leaves the inventory system open to stock-out because safety stock level does not protect against higher than expected demand, or longer than anticipated lead-time.

3. Warehouse and Production

The MCI warehouse is divided into four sections: exam storage, bulk inventory, course processing, and production. The exam storage area is a locked room where all exam components are stored. The exam storage area has 22 shelving units, measuring 4 feet by 1 foot by 10 feet, and yielding a storage capacity of 880 cubic feet. The bulk inventory and processing areas are used to store printed components and packaged courses respectively. The storage units measure 9 feet long by 3.5 feet deep by 12.5 feet high. The bulk inventory section has 100 storage units with a storage capacity of 39,500 cubic feet. The processing area has 25 storage units with a storage capacity of 10,000 cubic feet. The production area is used to compile components for distribution as complete courses.

Fifteen personnel, who work one of two eight-hour shifts, staff the MCI warehouse. Warehouse operations are divided into two sections. The first receives and stores the components; the second produces, stores, and labels the courses. The day shift is normally responsible for the reception and staging of incoming component orders. Course production is currently done on demand. Each morning the warehouse personnel

are given a list of course requests (called a *run*) for the preceding 24 hours. Production of courses on the run then begins with the most requested course being produced first. Course production consists of gathering the components required for the course, combining these components into course units, shrink-wrapping the course units, and placing them into storage in the processing area. Once production meets the requirements of the day's run the courses are labeled with an address and transferred to the postal division for postage and mailing. After the day's run is completed, if significant work hours remain, production begins in anticipation of the next day's run.

B. EXPERIENCE TOUR OBSERVATIONS

A number of significant issues were presented during the author's visit to MCI. Some were resolved during the visit while the others guided the path of this thesis. They are listed as follows:

1) Print costs were not readily available. MCI component print cost data was collected; the 13 component print cost variables for each component were entered into an Excel spreadsheet for use in calculating print costs. The author wrote a Visual Basic "print cost calculator" based on the 1999 regular print contract. Working with MCI's database administrator the author was able to load the component cost variables data into their database and establish a dynamic link between this data and the print cost calculator (MCI is currently using this data and calculator to estimate the costs of all regular print jobs). MCI now has the ability to update data on revised components and, if necessary, to add new or delete obsolete components from their database.

2) MCI did not operate within its approved FY99 operating budget (OPTAR). Deputy Director, Col. Hamashin, and Operations Officer, Maj. Ackley, asserted opinions that with a more accurate, or scientific, inventory policy they would not be constrained by their current OPTAR. Appropriate application of basic inventory theory can allow for significant improvements in inventory management.

3) MCI wants to significantly reduce the number of backorders. The goal of inventory service level models is to determine reorder points and reorder quantities while minimizing cost subject to meeting a certain service level requirement. (Tersine, p. 232) MCI tracks every course request that cannot be met from available inventory. Their stated desire is to minimize the number of times that component shortages occur. This invites the application of an inventory service level model to establish reorder policies.

4) Holding costs are not relevant to this problem because the OPTAR does not pay holding costs. In an economic service level model, holding costs play an important role. Without holding costs, reorder quantity and reorder points become infinite. Because of the lack of holding cost we cannot use an economic, stochastic service level model. We must adapt some form of service level model to our particular problem, which leads to a non-linear program model. The primary goal of this problem is to minimize the expected number of shortages per year while ensuring that budget and warehouse capacity constraints are not violated.

III. MODEL FORMULATION

A. GENERAL DESCRIPTION

The model used to solve MCI's problem is a non-linear programming model that minimizes the expected number of "out-of-stock" components per year. This objective function is subject to constraints of budget, warehouse capacity, and an order quantity of the lesser of one year's expected demand or 10,000 copies.

The model is adapted from the service level model allowing backorders as described by Schrady and Choe. It ignores holding costs because holding costs are not paid from MCI's printing budget. The printing budget is only earmarked for component acquisition costs.

B. ASSUMPTIONS

Demand is normally distributed while lead-time is deterministic. This convolution results in a lead-time demand that is normally distributed. To validate the assumption of normal demand, the Kolmogorov-Smirnov goodness-of-fit test is applied to the demand data of each component. Results indicated that the null hypothesis (i.e. the data is normally distributed) could not be rejected at the 0.05 significance level.

Backorders are allowed with no lost sales. All backorders are filled immediately upon the receipt of an order. There is never a state where there are backorders and available inventory on hand at the same time.

Demand and lead-time are independent.

Demand is assumed to be random and stationary. Although it may vary from month to month, the expected demand does not change. It is noted that expected demand in reality changes. Therefore, reorder quantities are limited to no more than one year's expected demand.

Holding costs are ignored because they are not paid from MCI's print budget. Ignoring holding cost causes economic reorder points and reorder quantities to become unbounded. Safety levels are therefore restrained to three standard deviations of the expected lead-time demand. Safety levels are also constrained to be greater than or equal to zero.

Print orders for 278 of the 305 components will be costed at the regular print contracted price. Six components' costs are determined from the most recent order placed by MCI and only contain unit costs. The remaining 21 components are obtained free of charge when ordered from DAPS or the National Imagery and Mapping Agency (NIMA).

C. DATA COLLECTION

1. Print Costs

Costs associated with the regular print contract are dependent on the composition of the component. Component costs are a function of 13 variables: the number of text pages, paper size (8 ½ x 11, or 4 ½ x 5 ½ up to 8 ½ x 11), cover color, number of ink colors used on the cover, number of text pages with multiple colors, number of colors used on those pages, number of fold-in pages, number of colors on fold-ins, fold-ins

printed on one or two sides, number of pages with perforations, and the type of binding to be used. MCI has been using several different spreadsheets to estimate the cost of a print job depending on the makeup of the component. As mentioned in Chapter II, to aid in the cost estimation process, and also as a means of capturing print cost data, a Visual Basic program is developed that reads both the component characteristics and the quantity ordered, and returns the contractual set-up cost, per unit cost, and total order cost.

The component composition data is available only in archived hardcopy print requests. There is no single source where the component compositions are listed. The component composition data is entered into MCI's existing database and can be updated whenever a component revision occurs or a new component is added. With all of this information in the database and a dynamic link to the Visual Basic print cost calculator, the order set-up and unit costs for each component are obtained.

Costs for print on demand provided by the contractor are estimated by MCI to be three cents per page. Cost for in-house print jobs is determined by taking the purchase cost of the printer, printer maintenance costs, and paper costs and depreciation over a five-year period (expected lifetime of printer). This value is estimated to be 2 cents per page. (Allen)

All but two types of components can be printed under the regular print contract; therefore the regular print costs will be used to determine a base line. The cost data for the two exceptions, large posters and small cardboard aids, are determined as per-unit costs based on the most recent print requests. These two exceptions account for only six of 305 components. The cost data in Appendix A was primarily taken from the Visual

Basic print cost calculator discussed above. The Visual Basic form and code for the print cost calculator are in Appendix B. Cost data showing zero fixed cost and a positive unit cost are the six exceptions listed above. Cost data with zero fixed and zero unit costs are provided from other DoD agencies, DAPS (warfare publications) and NIMA (charts and maps).

Print option capacities:

Regular print	- Maximum of 12 orders per workday, maximum of 10,000 copies per order, maximum of 600 pages per order.
Print on demand	- Same as Regular print but limited to 1 order per workday
One-time	- No predetermined limits
In-house	- 91 pages per minute, 16 hours per day. Total of 87,360 pages per day

2. Volume

Although length and width measurements are available, MCI could not provide component thickness. To solve this problem the author solicited several Marine Corps officers to obtain copies of any courseware they might have. Maj. R.O. Baker provided 10 components from the Command and Staff College PME. With this data set the author ran a regression to determine the thickness of a component as function of the number of pages. The author used these components to form a data set of length, width, number of pages, and thickness (to an accuracy of 1/32 of an inch). The thickness of each unit was calculated using the resulting regression equation. The unit volume was then calculated

as the product of length, width, and thickness. The data set, regression and resulting equation are found in Appendix C.

3. Demand

Demand data is provided by Mr. Dave Robnett, database manager for MCI. Mr. Robnett provides a year of component demand data by monthly demand. From this data the mean monthly demand and standard deviation are calculated. Annual demand is simply twelve times the mean monthly demand. With a constant two-month order lead-time, expected lead-time demand is two times the mean monthly demand. The standard deviation of lead-time demand is the square root of two times the standard deviation of monthly demand. The demand data for each component is tested for normality using the Kolmogorov-Smirnov goodness-of-fit test. This test failed to reject the hypothesis that the data is normally distributed.

An examination of time of year, or seasonal, effects is not conducted on this data set as only one year's data is available, and there is no way to ensure that any patterns observed in 1999 hold true for previous years' demand. The issue of determining seasonal effects is further complicated by the fact that MCI began to offer on-line course registration in 1999, which resulted in an overall increase in course enrollments. Due to the fact that this increase only affects the three most recent months it is unknown whether on-line registration causes a permanent or temporary demand spike across all components. It is noted that if the demand spike is temporary, then this thesis overstates the variability, resulting in larger safety levels than what is required. If the spike in

demand is permanent, then this model understates mean demand while overstating the variance. The net result is uncertain.

4. Budget and Volume Limits

The FY1999 authorized print budget was \$1.075 million. MCI print costs ran over the approved print budget by \$300,000.00 making actual expenditures \$1.375 million in FY99. This happens to be the current FY2000 budget and is used as the maximum available budget.

Available storage capacity discussed above is calculated by measuring the dimensions of the shelving units, counting the number of units in each section of the warehouse and multiplying the dimensions and number. Component storage capacities in the bulk inventory and exam storage areas of the warehouse are the areas of concern for this model. These areas combined provide approximately 40,000 cubic feet, of available storage capacity. It is apparent from personal inspection of the warehouse and in the opinion of Maj. Ackley that the bulk inventory section of the warehouse is not efficiently managed, and that MCI's inventory policies should not be constrained by lack of component storage space.

Each data element, for all components, is provided in Appendix A.

D. FORMULATION

Index:

c Component (1...305).

Parameters:

Fix_c	Fixed set-up cost for each print job ($/order)
$Unit_c$	Cost to print each unit of component c ($/unit)
Vol_c	Unit volume of each component c (ft^3/unit)
R_c	Expected annual demand for component c (units/year)
$\overline{M}_c$	Expected lead-time demand for component c (units)
σ_c	Standard Deviation of lead-time demand (units)
Budget	Available regular print budget ($)
VolCap	Available warehouse storage capacity (ft^3)

Variables:

B_c	Reorder point for component c (units)
Q_c	Reorder quantity for component c (units/cycle)
Z_c	Normal deviate for each component c
SO_c	Expected stock-outs per cycle of component c (units/cycle).

Formulation:

$$Min \quad \sum_c SO_c \left(\frac{R_c}{Q_c} \right) \qquad (1)$$

Subject to:

$$\sum_c Fix_c\left(\frac{R_c}{Q_c}\right) + Unit_c R_c \leq Budget \tag{2}$$

$$\sum_c Vol_c\left(B_c - \overline{M}_c + Q_c\right) \leq VolCap \tag{3}$$

$$Z_c = \frac{B_c - \overline{M}_c}{\sigma_c} \quad \forall c \tag{4}$$

$$SO_c = \sigma_c\left(\varphi(Z_c) - Z_c\left(1 - \Phi(Z_c)\right)\right) \quad \forall c \tag{5}$$

$$Q_c \geq \frac{R_c}{4} \quad \forall c \tag{6}$$

$$Q_c \leq 10000 \quad \forall c \tag{7}$$

$$Q_c \leq R_c \quad \forall c \tag{8}$$

$$Z_c \leq 3 \quad \forall c \tag{9}$$

$$B_c, Q_c, SO_c, Z_c \geq 0 \quad \forall c \tag{10}$$

E. DESCRIPTION OF FORMULATION

Equation (1) is the objective function, minimizing the number of stock-outs (number of unmet demands) per year over all components.

The budget constraint, equation (2), is the product of set-up cost per order and the number of orders per year plus the product of the cost per unit and the annual demand which must be less than or equal to the annual budget.

The storage space requirements are determined using a static inventory level approach, where a specific amount of space is dedicated to each component. Expected storage space equals $B_c - \overline{M}_c + Q_c$. The bulk inventory capacity constraint, equation (3), is calculated by multiplying the expected storage space by the unit volume of each

component; this must be less than or equal to the available storage in the bulk inventory section of the warehouse.

The variable Z_c represents the standard normal deviate of lead-time demand and is calculated in equation (4).

The expected number of stock-outs per cycle is derived using equation (5). Units short per cycle are determined by the partial expectation of Z_c times the standard deviation of lead-time demand (Tersine, pp. 218-222).

Equations (6), (7), and (8) establish upper and lower bounds on the reorder quantity for each component. The lower bound on reorder quantity is set to be no less than one fourth of annual demand. This limits the number of orders per year and thus the number of times the set-up cost will be incurred. The upper bound of 10,000 is a contract constraint stated in the 1999 regular print contract. Equation (8) limits the reorder quantity to be no greater than the annual demand.

Equation (9) ensures that the standard normal variate of lead-time demand in no more than three. This ensures that safety stock levels are bounded to be no more than three standard deviations of lead-time demand.

Equation (10) establishes the reorder point, reorder quantity, safety stock level and expected shortages as positive variables.

F. CONVEXITY

Because this model is a non-linear programming model, one has to determine that the objective function is convex and the constraints constitute a convex feasible region in

order to ensure that the non-linear programming solver produces a globally optimal solution. In this case, the objective function and constraints possess the required convexity for global optimality, as proved in Appendix D.

IV. RESULTS

The NLP model presented in chapter III is programmed into GAMS using the MINOS5 NLP solver. To evaluate the model's performance, a comparison is drawn between the expected output using the current MCI inventory procedures and the output using the resultant decision variables of the NLP model (called the optimization model). Later, a heuristic is proposed as an alternative to using the NLP; the output of the heuristic is compared with the output of the optimization model. The outputs resolve five issues: (1) When should a component be reordered? (2) What quantity should be ordered? (3) How much will this inventory cost? (4) How much storage space is required? (5) To what extent does this policy reduce shortages? The first two issues deal with determining the decision variables; the latter three deal with performance factors of the model.

A. EVALUATION OF CURRENT MCI POLICY

The initial step in the evaluation is to examine the level of service MCI is currently providing. It is known that MCI spent \$1.375M in FY99 on printing costs, and is using most of its 40,000 ft^3 of warehouse space while operating an inventory system as discussed in Chapter II. MCI maintains some historical records, but does not record the number of unfilled requests (i.e., the number of students who had to wait because MCI was out of stock) and therefore, the number of shortages per year is not known.

The next step is to evaluate the expected performance measures using the current inventory policy subject to the constraints detailed in the NLP model. The decision variables (reorder points and reorder quantities) generated from this policy produce a value for the expected warehouse requirement, the annual budget and the expected shortages. These variables are later used as the initial feasible solution for the optimization model.

1. Determination of an Initial Feasible Solution

An initial feasible solution is needed to solve the NLP. To accomplish this, an algorithm, written in GAMS, is developed using MCI's current inventory policy as explained in Chapter II and is displayed in detail in Appendix E. The following describe the highlights of the algorithm:

a) Variable Bounds

Upper and lower bounds are placed on the decision variables in order to ensure a realistic implementation of MCI's current inventory policy. Additional explanation of the variable bounds can be found in Chapter III, section E.

b) Setting Reorder Points and Reorder Quantities

An initial solution is determined by setting the component reorder points at three months worth of demand and the component reorder quantities at six months worth of demand. This is an optimistic implementation of MCI's stated inventory policy because this actual policy is to set reorder points between two and three months worth of demand and to set reorder quantities between four and six months of demand.

c) Adjusting for Feasibility

The budget and capacity constraints are then checked to determine feasibility. If infeasible in the budget constraint ($1.375M), the reorder quantities are increased by 10 percent. By increasing the reorder quantities the number of order cycles per year is reduced and subsequently, the number of times the order set-up cost is incurred is reduced, thus reducing overall budget requirements. If infeasible in the warehouse constraint (40,000ft^3), the reorder points are decreased by 10 percent. Reducing the reorder points decreases the amount of storage space required for those components and therefore the overall storage capacity requirement is reduced.

2. Determination of Performance Factors

Once reorder quantities and reorder points are established, the expected number of shortages are calculated along with the annual cost of operating the inventory system and the warehouse requirement. The expected result of operating the MCI inventory system is 5000 component shortages, while utilizing 10,000ft^3 of warehouse space and $905K of OPTAR.

This algorithm is an optimistic implementation of MCI's stated inventory policy. For example, costs used in evaluating the budget are extracted from the regular print contract. In other words, the algorithm assumes a policy that all print purchase orders use the regular print contract. This is not always the case as MCI readily admits. (Ackley) In fact, MCI used the more expensive print on demand option on a number of occasions, which partially explains the difference in the actual OPTAR spent in FY99 and the expected cost to maintain the inventory. Another example helps to explain the disparity

between actual warehouse usage and expected requirements. This is due in part to the storage of obsolete components and the fact that MCI uses the bulk inventory portion of the warehouse to store other items that are not modeled in this thesis.

B. DETERMINING AN OPTIMAL SOLUTION

1. GAMS Model

In order to ensure proper model performance of a non-linear program, an initial feasible solution must be provided. The current policy algorithm is now used as the initial starting point for the GAMS model discussed in Chapter III. The reorder points and reorder quantities are extracted from the current policy algorithm and input into the GAMS NLP model as an initial feasible solution for this optimization model.

2. Results

The optimization model returns a global optimal solution. The solution yields an expected shortage of only 33 components per year while using 16,750ft^3 of warehouse space and requiring an OPTAR of $790,000. The resulting solution provides a significant improvement in projected levels of service from the initial feasible solution.

In evaluating the results of the optimization model it is important to note that neither the budget constraint nor the warehouse capacity constraint are binding. The only binding constraints are the upper bounds placed on the reorder quantities and reorder points.

C. HEURISTIC DEVELOPMENT

1. Motivation

After noting the significant improvement in service indicated by the results of the optimization model, it is desirable to determine an implementable inventory policy that more closely approximates this optimal solution. MCI does not have the GAMS software or the expertise needed to use it. A heuristic that meets this criterion would enable MCI to quickly and easily reprogram their inventory management information system, and immediately implement a more efficient inventory policy. A heuristic is developed that provides this approximation.

2. Procedures

This heuristic establishes the reorder point for each component as the average lead-time demand plus three standard deviations of lead-time demand. The reorder point is set at this level after noting that this constraint is binding in the optimal solution. The heuristic establishes the reorder quantities as the lesser of a year's worth of demand or 10,000. The reorder quantities are set at their maximum feasible limit in order to minimize cost and because the associated model constraints are binding in the optimal solution. The budget and capacity constraints are then checked to determine feasibility. If infeasible in the budget constraint ($1.375M), the reorder quantities are increased by 10 percent. By increasing the reorder quantities the number of order cycles per year is reduced and subsequently the number of times the order set-up cost is incurred is reduced, thus reducing overall budget requirements. If infeasible in the warehouse constraint (40,000ft^3), the reorder points are decreased by 10 percent. Reducing the

reorder points decreases the amount of storage space required for those components and therefore the overall storage capacity requirement is reduced. Details of the heuristic are described in Appendix F.

3. Results

Evaluation of the heuristic solution yields the same solution as the optimization model. This is not surprising because the results of the optimization model are used in establishing the heuristic. The simplicity of the heuristic enables MCI to program it into its inventory management information system and immediately begin managing its inventory under a new set of procedures that reduces the expected number of shortages while staying within warehouse capacity and operating budget.

D. COMPARISON OF THE MODELS

The non-linear programming model developed in Chapter III is used to evaluate MCI's current inventory system and to determine an optimal solution. The heuristic is developed to provide verification of the model result and as an "easy-to-implement" inventory management tool. In each case, the resulting optimal solution yields an expected number of yearly shortages to be 33 components, while using 16,750ft^3 of warehouse space and \$790K of OPTAR. The results of the initial feasible solution, the optimization model output, and heuristic are compared to the actual FY99 baseline in Table 1.

Table 1. Comparison of Results

Category	FY99 Actual Results	Estimated MCI Current Policy Results	Optimization Model Results	Heuristic Results
Shortages	Unknown	5,000 units	33 units	33 units
Budget	$1,375,000	$905,000	$790,000	$790,000
Volume	40,000 ft (capacity)	10,000 ft^3	16,750 ft^3	16,750 ft^3

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V. CONCLUSIONS

A. OVERVIEW

Improved service is achievable by MCI. Evaluation of the model presented in this thesis resolves the five issues posed by MCI. In analyzing the results of the model it is apparent that MCI can improve service level to the Marine Corps while decreasing its printing budget and reallocating excess warehouse space to the processing area for course storage. Adopting this inventory policy, assuming adequate safety levels are on hand, can reduce OPTAR by $585,00. (If it is assumed that MCI must purchase safety stock, the value of that stock is $70,100, then adopting this inventory policy would result in an OPTAR reduction of $515,000.) It also allows course storage in anticipation of demand to increase, and improves service by 99.3 percent.

B. RECOMMENDATIONS

1) It is recommended that MCI use the reorder points and reorder quantities calculated in this thesis to manage its inventory of course components. This can be immediately implemented by using the heuristic algorithm presented in Chapter 4 and detailed in Appendix F to manage its inventory. The author has already provided MCI's systems manager with the heuristic.

2) MCI currently packages the vast majority of its courses after receiving demands for them. The course packaging section of the warehouse is used to store

packaged courses. The shelving units in this section of the warehouse are almost bare because MCI does not try to fully stock packaged courses. It is recommended that MCI produce courses in anticipation of demand, which will decrease student request processing time. An inventory production model would be well suited to determine the best schedule of course packaging/production.

3) It is recommended that storage space be identified and dedicated for each component using equation (3) presented in the model. Currently the bulk inventory section of MCI's warehouse is essentially full. Observation by the author and confirmation by MCI indicate that there is no structure or organization to the storage of components in this section of the warehouse. Evaluation of current and optimal inventory policies indicates that the storage requirement is well below the 40,000 ft^3 available. This excess storage space could be converted to packaged course storage, and coupled with the course production model, could have a significant impact on further reducing course request fill times.

4) It is recommended that MCI remove all obsolete material from its shelves for recycling.

C. SUGGESTED MODEL IMPROVEMENTS

1. Develop modern inventory techniques to better:
   - (a) Forecast demand and variance of demand that puts more weight on recent data;
   - (b) Forecast lead-time and variance of lead-time;

(c) Determine the unit volume of each component.

2. Establish a management information system to capture the required data to calculate 1(a), (b), and (c).

3. Develop an inventory production model. Determination of a course production scheduling model will allow faster course request turn around time if courses can be made in anticipation of demand instead of producing the previous day's demand. Data on how many man-hours are involved in setting up the production of each course and the number of man-hours required to produce one unit of each course is required. Other factors will be the amount of available storage and the unit volume of each course.

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APPENDIX A. MODEL DATA

Parent: Lists the 151 course numbers. An empty entry in the parent column denotes a component that is used in multiple courses.

Component: Lists the 305 individual components.

Unit cost: The individual unit cost of each component ($).

Set-up cost: The fixed order set-up cost for each component ($).

Volume: The individual unit volume (ft^3).

LTD: Expected lead-time demand for each component (units).

SD LTD: Standard deviation of lead-time demand for each component (units).

Annual Demand: Annual demand (1999) for each component (units).

Parent	Component	Unit cost ($)	Set Up cost ($)	volume (ft3)	LTD (units)	SD LTD	Annual Demand
001A	EXAM C	0.0740	170.00	0.00230	1589.6667	462.4885	9538
001A	TEXTBOOK	0.4552	300.00	0.01239	1589.6667	462.4885	9538
0112B	EXAM E	0.0415	114.00	0.00115	1549.1667	308.2676	9295
	NAVMC 2795	0.2848	538.00	0.00186	7523.6667	2758.1314	45142
0112B	TEXTBOOK	0.4274	270.00	0.01102	1549.1667	308.2676	9295
0118J	DICTIONARY	2.3000	0.00	0.00555	2416.0000	438.5090	14496
0118J	EXAM G	0.0553	142.00	0.00161	2416.0000	438.5090	14496
0118J	TEXTBOOK	0.6994	470.00	0.02020	2416.0000	438.5090	14496
0119G	EXAM I	0.0415	114.00	0.00115	724.5000	151.6421	4347
0119G	TEXTBOOK	0.5875	405.00	0.01721	724.5000	151.6421	4347
0131H	EXAM M	0.0740	170.00	0.00230	294.6667	39.7873	1768
0131H	STUDENT REF.	1.3261	1,015.00	0.04522	294.6667	39.7873	1768
0131H	TEXTBOOK	0.4867	325.00	0.01354	294.6667	39.7873	1768
0138A	TEXTBOOK	0.4300	280.00	0.01148	116.8333	19.6927	701
0143A	TEXTBOOK	0.5912	400.00	0.01699	203.8333	36.9248	1223
0144	EXAM A	0.0667	170.00	0.00195	150.1667	35.0141	901
0144	TEXTBOOK	0.5875	405.00	0.01721	150.1667	35.0141	901
0201	EXAM A	0.0691	170.00	0.00207	503.3333	81.1359	3020
0201	READINGS	1.5214	1,170.00	0.05233	503.3333	81.1359	3020
0201	SWA TEXTBOOK	0.9151	665.00	0.02915	503.3333	81.1359	3020
0210B	EXAM E	0.1081	254.00	0.00333	4094.6667	582.6137	24568
0210B	TEXTBOOK	1.1404	820.00	0.03627	4094.6667	582.6137	24568
028B	EXAM E	0.0740	170.00	0.00230	422.6667	65.8796	2536
028B	TEXTBOOK	1.0218	710.00	0.03122	422.6667	65.8796	2536
0316J	EXAM R	0.0529	142.00	0.00149	655.8333	89.5188	3935

Parent	Component	Unit cost	Set Up cost	volume	LTD	SD LTD	Annual
		($)	($)	(ft3)	(units)		Demand
0316J	GTA 21-2-7	0.0200	0.00	0.00001	655.8333	89.5188	3935
0316J	TEXTBOOK	0.7316	440.00	0.01882	655.8333	89.5188	3935
0321A	EXAM A	0.0691	170.00	0.00207	175.6667	101.3811	1054
0321A	TEXTBOOK	0.8995	641.00	0.02640	175.6667	101.3811	1054
0322J	TEXTBOOK	0.7104	502.50	0.02169	149.6667	40.4602	898
0324G	TEXTBOOK	0.9427	705.00	0.02961	427.1667	76.5731	2563
0331J	GTA 7-1-29	1.0000	0.00	0.00012	111.3333	31.1263	668
0331J	TEXTBOOK	1.0075	742.50	0.03179	111.3333	31.1263	668
0332G	EXAM G	0.1678	198.00	0.00275	553.0000	115.0802	3318
0332G	TEXTBOOK	1.1521	847.00	0.03604	553.0000	115.0802	3318
0335C	TEXTBOOK	0.5938	410.00	0.01744	736.1667	151.0707	4417
0338	TEXTBOOK	0.7309	519.00	0.02135	108.6667	23.3887	652
033N	EXAM A	0.0578	142.00	0.00172	6897.0000	963.5005	41382
033N	TEXTBOOK	0.7261	515.00	0.02226	6897.0000	963.5005	41382
034N	TEXTBOOK	0.8773	635.00	0.02777	300.8333	71.3696	1805
0354B	EXAM E	0.0602	142.00	0.00184	562.6667	139.2465	3376
0354B	TEXTBOOK	0.5182	350.00	0.01469	562.6667	139.2465	3376
0355B	TEXTBOOK	0.6442	450.00	0.01928	116.1667	32.0480	697
0365	EXAM A	0.0602	142.00	0.00184	180.0000	37.6636	1080
0365	TEXTBOOK	0.4389	295.00	0.01217	180.0000	37.6636	1080
0366B	TEXTBOOK	0.7261	515.00	0.02226	418.8333	110.2187	2513
0368	EXAM A	0.0578	142.00	0.00172	174.5000	31.6407	1047
0368	TEXTBOOK	0.5241	315.00	0.01308	174.5000	31.6407	1047
0370A	TEXTBOOK	0.6509	447.00	0.01676	446.6667	93.3251	2680
0372A	EXAM A	0.0464	114.00	0.00138	117.6667	72.7907	706
0372A	TEXTBOOK	0.7292	517.50	0.02238	117.6667	72.7907	706
0380	EXAM A	0.1240	114.00	0.00126	278.0000	57.1314	1668
0380	TEXTBOOK	0.4252	300.00	0.01239	278.0000	57.1314	1668
0381B	EXAM E	0.1105	254.00	0.00344	1061.1667	197.1852	6367
	G.T.A. 5-2-12	0.5000	0.00	0.00003	4115.6667	686.3089	24694
0381B	MARGARITA PEAK MAP	0.0000	0.00	0.00082	1061.3333	197.1850	6368
0381B	TEXTBOOK	1.2237	1,135.00	0.03420	1061.1667	197.1852	6367
0382	TEXTBOOK	0.5660	380.00	0.01607	170.0000	35.4965	1020
0383	EXAM A	0.0829	198.00	0.00252	282.0000	34.2504	1692
0383	TEXTBOOK	0.5912	412.00	0.01699	282.0000	34.2504	1692
0410B	EXAM E	0.1905	254.00	0.00344	356.1667	71.1016	2137
0410B	STUDENT REF.	0.3654	252.50	0.01021	356.1667	71.1016	2137
0410B	TEXTBOOK	1.0411	765.00	0.03374	356.1667	71.1016	2137
0414A	STUDENT REF.	0.6457	475.00	0.02043	68.6667	21.3910	412
0414A	TEXTBOOK	0.3999	618.00	0.00941	68.6667	21.3910	412
0416A	EXAM A	0.0439	114.00	0.00126	58.8889	30.4065	353
0416A	TEXTBOOK	0.7009	495.00	0.02135	58.8889	30.4065	353
045C	TEXTBOOK	0.5875	405.00	0.01721	130.6667	33.7495	784
047D	TEXTBOOK	0.5634	382.00	0.01561	112.6667	22.0688	676
0481A	BEACHMARKER	0.4744	602.00	0.00120	82.6667	16.8559	496
0481A	EXAM C	0.0415	114.00	0.00115	82.6667	16.8559	496
0481A	TEXTBOOK	0.9340	680.00	0.02984	82.6667	16.8559	496

Parent	Component	Unit cost	Set Up cost	volume	LTD	SD LTD	Annual
		($)	($)	(ft3)	(units)		Demand
0813 A	EXAM A	0.0967	226.00	0.00298	27.0000	13.0245	162
0813A	TEXTBOOK	1.3246	990.00	0.04407	27.0000	13.0245	162
0816A	TEXTBOOK	0.4689	295.00	0.01217	35.3333	14.6391	212
0820D	EXAM E	0.1016	226.00	0.00321	121.8333	19.3763	731
0820D	STUDENT REF.	0.5638	410.00	0.01744	121.8333	19.3763	731
0820D	TEXTBOOK	0.7917	575.00	0.02502	121.8333	19.3763	731
0861	TEXTBOOK	0.4489	295.00	0.01217	167.6667	45.7775	1006
1122A	EXAM C	0.0602	142.00	0.00184	116.1667	24.6315	697
1122A	TEXTBOOK	0.7676	540.00	0.02341	116.1667	24.6315	697
1141A	EXAM C	0.0439	114.00	0.00126	401.5000	105.7478	2409
1141A	TEXTBOOK	0.8206	590.00	0.02571	401.5000	105.7478	2409
1142B	TEXTBOOK	0.7041	497.50	0.02146	273.8333	60.0862	1643
1143	TEXTBOOK	0.6405	455.00	0.01951	366.1667	69.2150	2197
1161	TEXTBOOK	0.7665	555.00	0.02410	167.1667	27.8598	1003
1169	TEXTBOOK	1.0248	760.00	0.03351	70.8333	13.5842	425
1328E	ENGINEER EQUIP	1.6963	1,285.00	0.05761	41.6667	10.7858	250
1330A	TEXTBOOK	0.6505	455.00	0.01951	146.8333	48.2699	881
1332G	EXAM O	0.0602	142.00	0.00184	262.1667	48.9915	1573
1332G	TEXTBOOK	1.0789	795.00	0.03512	262.1667	48.9915	1573
1334H	EXAM J	0.0740	170.00	0.00230	3054.5000	568.9324	18327
1334H	TEXTBOOK	1.0096	740.00	0.03259	3054.5000	568.9324	18327
1335C	EXAM G	0.0302	86.00	0.00080	296.3333	62.1869	1778
1335C	TEXTBOOK	0.6379	445.00	0.01905	296.3333	62.1869	1778
1343	HANDBOOK 13.43-1	0.2181	310.00	0.00436	167.6667	44.9437	1006
1343	HANDBOOK 13.43-2	0.2181	310.00	0.00436	167.6667	44.9437	1006
1343	HANDBOOK 13.43-3	0.1767	226.00	0.00298	167.6667	44.9437	1006
1343	TEXTBOOK	0.7828	560.00	0.02433	167.6667	44.9437	1006
1344C	EXAM M	0.1357	310.00	0.00425	135.0000	31.4585	810
1344C	TEXTBOOK	1.0170	742.00	0.03213	135.0000	31.4585	810
1373	TEXTBOOK	0.5660	380.00	0.01607	182.1667	33.2564	1093
1391	EXAM A	0.0829	198.00	0.00252	108.0000	20.5205	648
1391	HANDBOOK	0.2871	450.00	0.00666	108.0000	20.5205	648
1391	TEXTBOOK	0.9414	682.00	0.02938	108.0000	20.5205	648
1831B	TEXTBOOK	0.6757	475.00	0.02043	57.8333	12.2468	347
1833B	TEXTBOOK	0.5875	405.00	0.01721	77.1667	25.5233	463
1834C	EXAM G	0.1129	258.00	0.00252	15.3333	7.2195	92
1834C	TEXTBOOK	1.1230	830.00	0.03672	15.3333	7.2195	92
1843A	TEXTBOOK	0.5875	405.00	0.01721	74.8333	14.1737	449
1844	EXAM A	0.0578	142.00	0.00172	49.1667	9.4860	295
1844	TEXTBOOK	0.5775	405.00	0.01721	49.1667	9.4860	295
1846	HANDBOOK	0.1398	30.00	0.00200	48.8333	11.8392	293
1846	TEXTBOOK	0.6820	480.00	0.02066	48.8333	11.8392	293
1851	TEXTBOOK	0.6694	470.00	0.02020	67.1667	17.4404	403
2124F	TEXTBOOK	0.4993	335.00	0.01400	136.6667	35.1068	820
2135	EXAM A	0.0326	86.00	0.00092	217.5000	64.5379	1305
2135	TEXTBOOK	0.5623	385.00	0.01630	217.5000	64.5379	1305
2515G	TEXTBOOK	0.6883	485.00	0.02089	228.0000	52.4352	1368

Parent	Component	Unit cost	Set Up cost	volume	LTD	SD LTD	Annual
		($)	($)	(ft3)	(units)		Demand
2525A	TEXTBOOK	0.3418	210.00	0.00826	201.5000	49.0755	1209
2526B	TEXTBOOK	0.4395	287.50	0.01182	111.8333	25.5944	671
2532E	HANDBOOK	0.1780	282.00	0.00201	146.0000	43.7638	876
2532E	TEXTBOOK	0.5938	410.00	0.01744	146.0000	43.7638	876
2538A	TEXTBOOK	0.5371	365.00	0.01538	169.6667	58.8429	1018
2540	EXAM U	0.0667	170.00	0.00195	65.1667	18.5419	391
2540	TEXTBOOK	0.8180	580.00	0.02525	65.1667	18.5419	391
2551D	TEXTBOOK	0.6631	465.00	0.01997	79.6667	22.1551	478
2552C	TEXTBOOK	0.4804	320.00	0.01331	59.8333	20.6394	359
2820	EXAM A	0.0553	142.00	0.00161	327.6667	82.0595	1966
2820	TEXTBOOK	0.8884	620.00	0.02708	327.6667	82.0595	1966
286G	EXAM J	0.0740	170.00	0.00230	287.8333	68.1188	1727
286G	TEXTBOOK	0.7235	505.00	0.02181	287.8333	68.1188	1727
287	TEXTBOOK	0.4426	290.00	0.01194	97.8333	24.3867	587
301N	EXAM K	0.0439	114.00	0.00126	318.5000	49.3858	1911
301N	TEXTBOOK	0.5119	345.00	0.01446	318.5000	49.3858	1911
303H	TEXTBOOK	0.6946	490.00	0.02112	192.1667	38.3878	1153
3316E	EXAM G	0.0602	142.00	0.00184	1228.0000	230.8136	7368
3316E	TEXTBOOK	0.7342	498.00	0.01928	1228.0000	230.8136	7368
3333	TEXTBOOK	1.0255	741.00	0.03099	45.0000	18.7180	270
334L	EXAM C	0.0602	142.00	0.00184	132.5000	37.2467	795
334L	TEXTBOOK	1.0122	750.00	0.03305	132.5000	37.2467	795
3410A	TEXTBOOK	0.3570	230.00	0.00918	187.8333	39.2866	1127
3412	TEXTBOOK	0.3203	185.00	0.00712	70.0000	14.3843	420
3414	EXAM A	0.0464	114.00	0.00138	287.3333	73.5399	1724
3414	TEXTBOOK	0.4830	330.00	0.01377	287.3333	73.5399	1724
3420E	EXAM I	0.0716	170.00	0.00218	6626.3333	915.3886	39758
3420E	TEXTBOOK	0.6159	427.50	0.01825	6626.3333	915.3886	39758
3422A	TEXTBOOK	1.2816	952.00	0.04177	143.8333	82.4345	863
3503	EXAM A	0.0464	114.00	0.00138	155.3333	33.4030	932
3503	TEXTBOOK	0.5938	410.00	0.01744	155.3333	33.4030	932
3513B	EXAM G	0.0602	142.00	0.00184	111.6667	24.8913	670
3513B	TEXTBOOK	0.7324	520.00	0.02249	111.6667	24.8913	670
3515B	TEXTBOOK	0.4741	315.00	0.01308	213.3333	42.0923	1280
3520	3522 TEXTBOOK	0.3545	30.00	0.01262	4.1667	1.7538	25
3521	TEXTBOOK	0.5603	30.00	0.02226	10.5000	1.9188	63
3525B	TEXTBOOK	0.4374	282.00	0.01102	167.3333	35.1223	1004
3530	TEXTBOOK	0.9025	655.00	0.02869	148.8333	48.2209	893
3538B	TEXTBOOK	0.4578	310.00	0.01285	165.1667	23.5292	991
3580A	TEXTBOOK	0.6064	420.00	0.01790	275.0000	119.4708	1650
359F	TEXTBOOK	0.5334	370.00	0.01561	178.5000	29.6962	1071
571	EXAM A	0.0553	142.00	0.00161	478.1667	64.6008	2869
571	TEXTBOOK	0.6064	420.00	0.01790	478.1667	64.6008	2869
5710	EXAM A	0.0464	114.00	0.00138	104.3333	18.4177	626
5710	TEXTBOOK	0.5686	390.00	0.01653	104.3333	18.4177	626
5714A	TEXTBOOK	0.6642	490.00	0.01928	53.5000	24.2346	321
5812A	EXAM C	0.0553	142.00	0.00161	234.6667	51.2865	1408

Parent	Component	Unit cost	Set Up cost	volume	LTD	SD LTD	Annual
		($)	($)	(ft3)	(units)		Demand
5812A	TEXTBOOK	0.4882	350.00	0.01469	234.6667	51.2865	1408
581D	CORRECTIONS	1.5529	1,195.00	0.05348	502.1667	79.6845	3013
581D	EXAM N	0.0829	198.00	0.00252	502.1667	79.6845	3013
581D	TEXTBOOK	0.3485	534.00	0.00803	502.1667	79.6845	3013
582	EXAM A	0.1402	142.00	0.00184	328.0000	47.8292	1968
582	TEXTBOOK	0.4552	300.00	0.01239	328.0000	47.8292	1968
6001A	TEXTBOOK	0.7009	495.00	0.02135	221.6667	110.5438	1330
602A	TEXTBOOK	1.0348	760.00	0.03351	161.1667	43.1760	967
605	EXAM A	0.0415	114.00	0.00115	172.3333	58.8460	1034
605	TEXTBOOK	0.6789	477.50	0.02054	172.3333	58.8460	1034
606A	EXAM E	0.0464	114.00	0.00138	117.8333	33.7179	707
606A	TEXTBOOK	0.5875	405.00	0.01721	117.8333	33.7179	707
7103	TEXTBOOK	1.0807	773.00	0.03190	1249.3333	235.7443	7496
7104F	TEXTBOOK	0.7035	505.00	0.02181	1246.3333	237.6620	7478
7105F	TEXTBOOK	0.6764	468.00	0.01790	1249.8333	235.1467	7499
7106B	TEXTBOOK	0.5460	380.00	0.01607	1243.1667	235.6534	7459
7107C	TEXTBOOK	0.5712	400.00	0.01699	1251.5000	232.9449	7509
7108E	TEXTBOOK	0.6920	480.00	0.02066	1243.1667	236.7526	7459
7109B	TEXTBOOK	0.7450	530.00	0.02295	1249.3333	235.6448	7496
7110	TEXTBOOK	0.7350	530.00	0.02295	1249.8333	237.4129	7499
7201A	TEXTBOOK	0.5334	370.00	0.01561	398.6667	74.7002	2392
7202A	TEXTBOOK	0.6216	440.00	0.01882	399.1667	75.7423	2395
7203A	TEXTBOOK	0.6909	495.00	0.02135	400.5000	75.5179	2403
7205	TEXTBOOK	0.9854	690.00	0.02479	401.6667	74.6138	2410
7401A	EXAM A	0.0691	170.00	0.00207	1072.6667	122.9476	6436
7401A	TEXTBOOK	0.6720	480.00	0.02066	1072.6667	122.9476	6436
7402A	EXAM A	0.0602	142.00	0.00184	1074.1667	123.8261	6445
7402A	TEXTBOOK	0.4704	320.00	0.01331	1074.1667	123.8261	6445
7403B	EXAM A	0.0602	142.00	0.00184	1059.5000	130.2726	6357
7403B	TEXTBOOK	0.5775	405.00	0.01721	1059.5000	130.2726	6357
7404A	TEXTBOOK	0.6268	460.00	0.01974	1089.3333	127.9777	6536
7405A	EXAM A	0.0878	198.00	0.00275	1113.8333	123.9567	6683
7405A	TEXTBOOK	0.4830	330.00	0.01377	1113.8333	123.9567	6683
8000	PACKING LIST	0.0277	86.00	0.00069	4458.0000	495.6322	26748
8001A	BASIC GRAMMAR	0.5727	425.00	0.01813	4458.0000	495.6322	26748
8001A	EXAM C	0.0602	142.00	0.00184	4458.0000	495.6322	26748
8002A	EXAM C	0.0553	142.00	0.00161	4495.6667	540.9389	26974
8002A	TEXTBOOK	0.6609	495.00	0.02135	4495.6667	540.9389	26974
8003	EXAM A	0.0553	142.00	0.00161	4495.6667	540.9389	26974
8003	TEXTBOOK	0.8236	640.00	0.02800	4379.6667	498.9210	26278
8004	EXAM A	0.0326	86.00	0.00092	4379.6667	498.9210	26278
8004	TEXTBOOK	0.3700	280.00	0.01148	4377.5000	504.4584	26265
8005	EXAM A	0.0829	198.00	0.00252	4377.5000	504.4584	26265
8005	FMFM 6-5	1.0800	905.00	0.01890	4409.8333	495.3568	26459
8005	TEXTBOOK	1.0678	810.00	0.03581	4409.8333	495.3568	26459
8006A	EXAM C	0.1016	226.00	0.00321	4507.6667	521.4779	27046
8006A	TEXTBOOK	1.4347	1,125.00	0.05027	4507.6667	521.4779	27046

Parent	Component	Unit cost	Set Up cost	volume	LTD	SD LTD	Annual
		($)	($)	(ft3)	(units)		Demand
8501	AWS INFO BROCHURE	0.0602	142.00	0.00184	470.6667	135.2242	2824
8501	EXAM A	0.1292	282.00	0.00413	470.6667	135.2242	2824
8501	LEAVENWORTH	0.3196	240.00	0.00964	470.6667	135.2242	2824
8501	MCDP 1-2	0.0000	0.00	0.00648	949.1667	334.7523	5695
8501	MCDP-1	0.0000	0.00	0.00594	949.1667	334.7523	5695
8501	TEXTBOOK VOL 1	1.2394	970.00	0.04315	470.6667	135.2242	2824
8501	TEXTBOOK VOL 2	1.4527	1,107.50	0.04946	470.6667	135.2242	2824
8502	COMMAND VOL 1	1.4410	1,130.00	0.05050	479.3333	131.9784	2876
8502	COMMAND VOL 2	1.9094	1,470.00	0.06610	479.3333	131.9784	2876
8502	COMMUNICATIONS	0.6646	490.00	0.02112	479.3333	131.9784	2876
8502	EXAM A	0.1154	254.00	0.00367	479.3333	131.9784	2876
8502	ORDERS HANDBOOK	0.4814	364.50	0.01480	479.3333	131.9784	2876
8502	ORGANIZE HANDBOOK	0.5716	440.00	0.01882	479.3333	131.9784	2876
8502	TASK ORGANIZATION	0.4393	335.00	0.01400	479.3333	131.9784	2876
8601	EXAM A	0.1243	282.00	0.00390	128.6667	24.4454	772
8601	INFO BROCHURE	0.0602	142.00	0.00184	128.6667	24.4454	772
8601	P. EX ATTACK	0.1868	338.00	0.00505	128.6667	24.4454	772
8601	PE OVERLAY	3.3300	0.00	0.00184	128.6667	24.4454	772
8601	PE SOLNS ATTACK	0.2396	234.00	0.00780	128.6667	24.4454	772
8601	PERUCKO JEZERO MAP	0.0000	0.00	0.00082	128.6667	24.4454	772
8601	SINJ CROATIA MAP	0.0000	0.00	0.00082	128.6667	24.4454	772
8601	SPLIT CROATIA MAP	0.0000	0.00	0.00082	128.6667	24.4454	772
8601	SVRLIKA CROATIA MAP	0.0000	0.00	0.00082	128.6667	24.4454	772
8601	TEXTBOOK VOL 1	1.5073	1,171.00	0.05073	128.6667	24.4454	772
8601	TEXTBOOK VOL 2	1.5418	1,210.00	0.05417	128.6667	24.4454	772
8601	TEXTBOOK VOL 3	1.2835	1,005.00	0.04476	128.6667	24.4454	772
8601	YUGO HANDBOOK	1.0362	954.00	0.00878	128.6667	24.4454	772
8602	CATLETT VIRGINIA MAP	0.0000	0.00	0.00082	130.6667	24.0177	784
8602	FAIRFAX VIRGINIA MAP	0.0000	0.00	0.00082	130.6667	24.0177	784
8602	MIDDLEBURG VA MAP	0.0000	0.00	0.00082	130.6667	24.0177	784
8602	N KOREA HANDBOOK	1.7574	1,626.00	0.01526	130.6667	24.0177	784
8602	P.EX DEFENSIVE	0.2708	222.00	0.00734	130.6667	24.0177	784
8602	P.EX INSERT	0.1545	30.00	0.00700	130.6667	24.0177	784
8602	PE OVERLAY	3.3300	0.00	0.00835	130.6667	24.0177	784
8602	PE SOLNS DEFENSIVE	0.1706	174.00	0.00551	130.6667	24.0177	784
8602	QUANTICO VA MAP	0.0000	0.00	0.00082	130.6667	24.0177	784
8602	TEXTBOOK VOL 1	1.1701	915.00	0.04063	130.6667	24.0177	784
8602	TEXTBOOK VOL 2	0.9528	742.50	0.03271	130.6667	24.0177	784
8603	BAHMADI MAP	0.0000	0.00	0.00082	130.5000	24.1294	783
8603	FROM THE SEA	0.3172	562.00	0.00872	130.5000	24.1294	783
8603	JASK MAP	0.0000	0.00	0.00082	130.5000	24.1294	783
8603	NOWDINI MAP	0.0000	0.00	0.00082	130.5000	24.1294	783
8603	SELF PACED TEXT	0.4414	814.00	0.01285	130.5000	24.1294	783
8603	TEXTBOOK VOL 1	1.4284	1,120.00	0.05004	130.5000	24.1294	783
8603	TEXTBOOK VOL 2	1.8379	1,445.00	0.06496	130.5000	24.1294	783
8603	TEXTBOOK VOL 3	1.1890	930.00	0.04132	130.5000	24.1294	783
8603	TEXTBOOK VOL 4	1.2393	835.00	0.03695	130.5000	24.1294	783

Parent	Component	Unit cost ($)	Set Up cost ($)	volume (ft3)	LTD (units)	SD LTD	Annual Demand
8604	EXAM A	0.1243	282.00	0.00390	129.8333	24.1846	779
8604	HANDBOOK	1.2363	967.50	0.04304	129.8333	24.1846	779
8604	JT PUB 3-07	0.2854	534.00	0.00477	129.8333	24.1846	779
8604	TEXTBOOK VOL 1	1.1606	907.50	0.04028	129.8333	24.1846	779
8604	TEXTBOOK VOL 2	1.1134	870.00	0.03856	129.8333	24.1846	779
8800	FM/FMFRP READINGS	1.2016	940.00	0.04177	478.5000	339.1595	2871
8800	FMFM READINGS	1.6426	1,290.00	0.05784	478.5000	339.1595	2871
8800	INFO GUIDE	0.1154	254.00	0.00367	478.5000	339.1595	2871
8800	MCDP2	0.0000	0.00	0.00616	478.5000	339.1595	2871
8800	MCDP4	0.0000	0.00	0.00702	478.5000	339.1595	2871
8800	MCDP-6	0.0000	0.00	0.00832	478.5000	339.1595	2871
8800	MCWP 01.1	0.0000	0.00	0.53555	478.5000	339.1595	2871
8800	MCWP 5-1	0.0000	0.00	0.01102	478.5000	339.1595	2871
8800	NDP1	0.0000	0.00	0.00504	478.5000	339.1595	2871
8800	READINGS VOL 1	1.3150	1,030.00	0.04591	478.5000	339.1595	2871
8800	READINGS VOL 2	1.3843	1,085.00	0.04843	478.5000	339.1595	2871
8800	READINGS VOL 3	1.2457	975.00	0.04338	478.5000	339.1595	2871
8801	COURSE BOOK	0.4267	325.00	0.01354	470.3333	340.3217	2822
8801	EXAM A	0.0943	226.00	0.00287	470.3333	340.3217	2822
8801	READINGS	0.4204	320.00	0.01331	470.3333	340.3217	2822
8802	COURSE BOOK	0.4015	305.00	0.01262	471.1667	339.5941	2827
8802	EXAM A	0.0805	198.00	0.00241	471.1667	339.5941	2827
8802	READINGS VOL 1	1.3717	1,075.00	0.04797	471.1667	339.5941	2827
8802	READINGS VOL 2	1.4599	1,145.00	0.05118	471.1667	339.5941	2827
8803	COURSE BOOK	0.4708	360.00	0.01515	474.0000	339.3357	2844
8803	EXAM A	0.0829	198.00	0.00252	474.0000	339.3357	2844
8803	READINGS	0.2125	155.00	0.00574	474.0000	339.3357	2844
8804	COURSE BOOK	0.6472	500.00	0.02158	499.8333	340.2787	2999
8804	EXAM A	0.0878	198.00	0.00275	499.8333	340.2787	2999
8804	MCWP 2-1 INTEL OPS	0.0000	0.00	0.00432	499.8333	340.2787	2999
8804	READINGS	0.3574	270.00	0.01102	499.8333	340.2787	2999
8805	COURSE BOOK	0.3574	270.00	0.01102	497.8333	341.1411	2987
8805	EXAM A	0.0602	142.00	0.00184	497.8333	341.1411	2987
8806	COURSE BOOK	0.2944	220.00	0.00872	478.5000	336.4051	2871
8806	EXAM A	0.1105	254.00	0.00344	478.5000	336.4051	2871
8806	READINGS	0.6976	540.00	0.02341	478.5000	336.4051	2871
8807	COURSE BOOK	0.3952	300.00	0.01239	478.8333	337.3924	2873
8807	EXAM A	0.0992	226.00	0.00310	478.8333	337.3924	2873
8807	READINGS	0.9559	745.00	0.03282	478.8333	337.3924	2873
8808	COURSE BOOK	0.3889	295.00	0.01217	478.6667	336.7817	2872
8808	EXAM A	0.0878	198.00	0.00275	478.6667	336.7817	2872
8808	READINGS	0.6535	505.00	0.02181	478.6667	336.7817	2872
8809	COURSE BOOK	0.3952	300.00	0.01239	480.0000	338.9068	2880
8809	EXAM A	0.0878	198.00	0.00275	480.0000	338.9068	2880
8809	READINGS	1.5009	1,177.50	0.05268	480.0000	338.9068	2880

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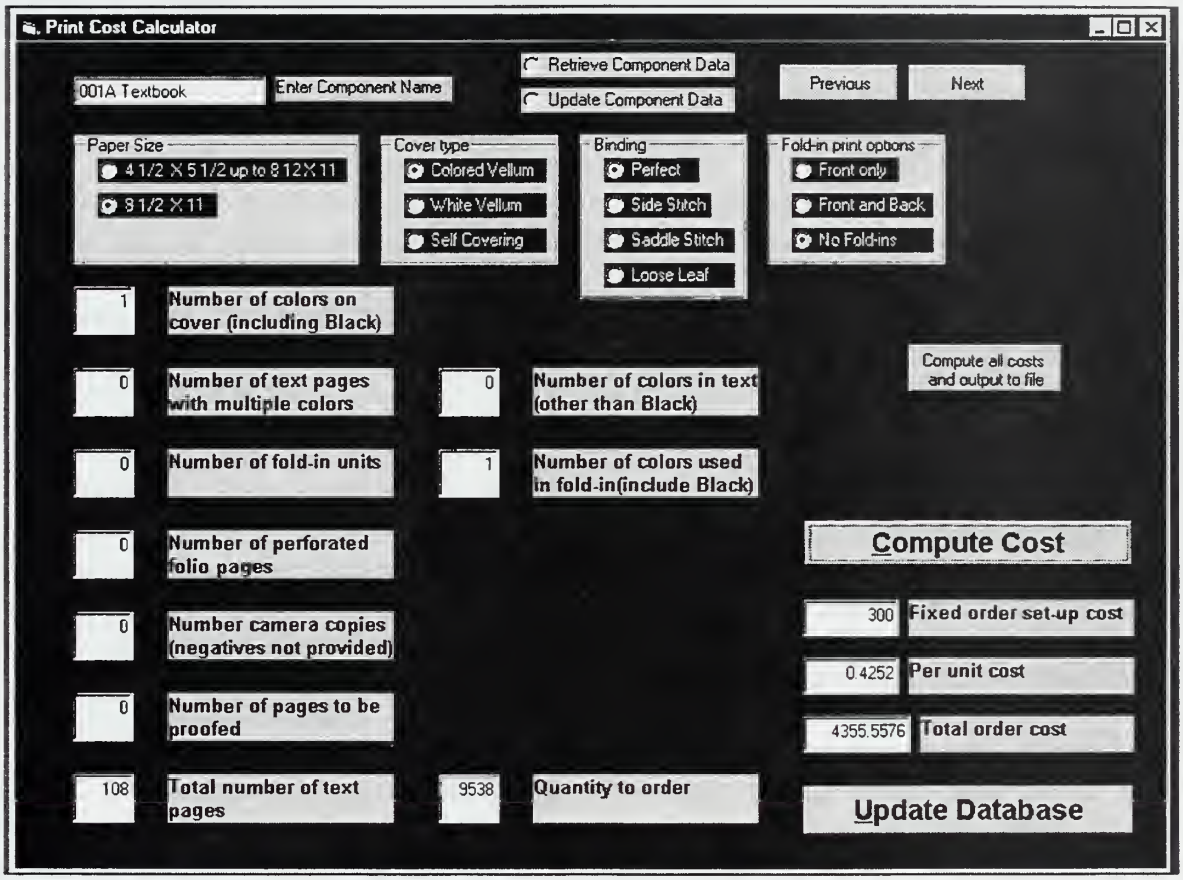
APPENDIX B. VISUAL BASIC FORM AND CODE

PRINT COST CALCULATOR FORM



PRINT COST CALCULATOR CODE.

```
'Input variables
    Dim qtyOrd, coverColors, clrdPages As Integer
    Dim textColors, foldIns, foldColors, negatives As
Integer
    Dim perforatedPages, proofPages, totalPages As Integer
    Dim txtExlFile As String
    Dim txtExcel As String
    Dim oConn As New ADODB.Connection
    Dim oRs As New ADODB.Recordset
```

```
    Dim fso As New FileSystemObject

Private Sub calculate_Click()

    Dim totlCost, fxdCost, untCost As Currency 'Output
variables
    Dim cvrCost, paperCost, bindCostUnit, bindCostFxd As
Double
    Dim negCost, proofCost, perfCost, compCvrFxd,
compCvrUnit As Double
    Dim foldCostUnit, foldCostFxd As Double

    qtyOrd = CInt(quantity.Text) 'quantity to be ordered
    coverColors = CInt(cvrColors.Text) 'number of colors
used on cover
    clrdPages = CInt(numClrdPages.Text) 'number of text
pages with additional colors
    textColors = CInt(numClrsText.Text) 'number of
additional colors used in text
    foldIns = CInt(numFold.Text) 'number of fold-ins
    foldColors = CInt(numFoldClrs.Text) 'number of ink
colors on fold-ins
    negatives = CInt(numNegs.Text) 'number of negative not
provided by Logs
    perforatedPages = CInt(numPerfPages.Text) 'number text
pages with perforations
    proofPages = CInt(numProofs.Text) 'number pages
requiring proofs
    totalPages = CInt(numTotalPages.Text) 'total text pages
in component

    'calculates per unit cost for paper size (cover
material and text stock)
    If bigPaper Then
        'calculates per unit cost of cover material
        If whiteCvr Then
            cvrCost = (2 * 25) / 1000 '2 cover leaves per
copy * $25 per 1000 leaves
        ElseIf colorCvr Then
            cvrCost = (2 * 40) / 1000 '2 cover leaves per
copy * $40 per 1000 leaves
        ElseIf selfCvr Then
            cvrCost = 0#
        End If

        'calculate per unit cost of text stock
```

```
        paperCost = (totalPages / 2) * (4.9 / 1000) '$4.9
per 1000 leaves

    ElseIf smallPaper Then
      'calculates per unit cost of cover material
       If whiteCvr Then
            cvrCost = (2 * 25) / 1000 '2 cover leaves per
copy * $25 per 1000 leaves
       ElseIf colorCvr Then
            cvrCost = (2 * 30) / 1000 '2 cover leaves per
copy * $30 per 1000 leaves
        ElseIf selfCvr Then
            cvrCost = 0#
       End If

       'calculate per unit cost of text stock
        paperCost = (totalPages / 2) * (4.4 / 1000) '$4.4
per 1000 leaves
    End If

    'calculates fixed and unit cost for binding options
    If perfectBind Then
        bindCostUnit = totalPages * (0.7 / 1000) +
textColors * clrdPages * (5 / 1000)
        bindCostFxd = totalPages * 2.5 + textColors *
clrdPages * 10
    ElseIf saddleBind Then
        bindCostUnit = Multiple(CInt(totalPages)) * (1 /
1000) + textColors * clrdPages * (5 / 1000)
        bindCostFxd = Multiple(CInt(totalPages)) * 7 +
textColors * clrdPages * 10
    ElseIf sideBind Then
        bindCostUnit = Multiple(CInt(totalPages)) * (1 /
1000) + textColors * clrdPages * (5 / 1000)
        bindCostFxd = Multiple(CInt(totalPages)) * 3 +
textColors * clrdPages * 10
    ElseIf looseBind Then
        bindCostUnit = 0#
        bindCostFxd = 0#
    End If

    'complete cover costs
    compCvrFxd = 30 + (coverColors - 1) * 20 '$30 one ink +
$20 each additional color
    compCvrUnit = (5 / 1000) + (coverColors - 1) * (5 /
1000) '$5 per 1000 copies one ink + $5 per 1000 copies
```

```
'each additional color
    'camera copy cost (negatives not provided)
    negCost = negatives * 1 '$1 for each negative missing

    'proof cost
    proofCost = proofPages * 1 '$1 per page for proof

    'perforation cost
    perfCost = (perforatedPages / 2) * (10 / 1000) '$10 per
1000 leaves

    'Calculate fixed and unit price for fold-in pages
    If frontPrint Then
        foldCostFxd = foldIns * 12 + foldIns * (foldColors
- 1) * 10

'$12 per fold-in + $10 each additional color
        foldCostUnit = foldIns * (20 / 1000) + foldIns *
(foldColors - 1) * (5 / 1000)

'$20 per 1000 + $5 per 1000 each additional color
    ElseIf twoSidePrint Then
        Dim front, back As Integer
        front = foldIns - (foldIns \ 2) 'number of front
sides
        back = foldIns \ 2 'number of backsides

        foldCostFxd = front * 12 + back * 8 + (foldColors -
1) * (front * 10 + back * 10)
                                '$12 per front + $8 per back + $10
per front and back each additional color
        foldCostUnit = front * (20 / 1000) + back * (8 /
1000) + (foldColors - 1) * (front * (5 / 1000) + back * (5
/ 1000))
                 '$20 per 1000 front + $8 per 1000 back +
$5 per 1000 per front and back each additional color
    ElseIf noFold Then
        foldCostUnit = 0#
        foldCostFxd = 0#
    End If

    untCost = CCur(paperCost + cvrCost + bindCostUnit +
compCvrUnit + perfCost + foldCostUnit)
    fxdCost = CCur(bindCostFxd + compCvrFxd + negCost +
proofCost + foldCostFxd)
```

```
    totlCost = CCur(fxdCost + untCost * qtyOrd)
    TotalCost.Text = totlCost
    unitCost.Text = untCost
    fixedCost.Text = fxdCost

    'This program can be modified to determine Economic
Reorder Quantity (EOQ) with slight modifications. _
    Two additional inputs are required, the inventory
holding cost per unit time and demand per unit _
    time (invHoldCost and demand below), unit time should
be 1 month.  The EOQ modifcation will utilize _
    all inputs from the current program EXCEPT the
quantityOrdered.  qtyOrd will be calculated as follows: _
    Sqr((2*fxdCost*demand)/invHoldCost).  This code should
be placed directly before the totlCost calculation _
    and the qtyOrd should be cast to integer and output to
quantity.Text
End Sub

Public Function Multiple(pages As Integer) As Integer
'rounds number of pages up to the nearest interval of 4

    Const interval = 4
    Dim modulo As Integer

    modulo = pages Mod interval

    If modulo = 0 Then
        Multiple = pages
    Else
        Multiple = pages + interval - modulo
    End If
End Function

Private Sub cmdCompAll_Click()
' Calculates fixed and unit costs for each component and
writes to file
    While Not oRs.EOF
        calculate_Click
        Set out =
fso.OpenTextFile("E:\Source\printcost\printcost.txt",
ForAppending, TristateFalse)
        out.WriteLine (CStr(componentName.Text) & ", " &
CStr(unitCost.Text) & ", " & CStr(fixedCost.Text))
        out.Close
```

```
        cmdNext_Click
    Wend
End Sub

Private Sub cmdNext_Click()
    If Not oRs.EOF Then
        oRs.MoveNext
    End If
    If Not oRs.BOF And Not oRs.EOF Then
        fillform
    End If
End Sub

Private Sub cmdPrev_Click()
    If Not oRs.BOF Then
        oRs.MovePrevious
    End If
    If Not oRs.BOF And Not oRs.EOF Then
        fillform
    End If
End Sub

Private Sub Form_Load()
'Opens and retrieves data from file
    Dim txtConn As String
    txtExlFile = "E:\Source\printcost\componentData.xls"
    txtConn = "DRIVER={Microsoft Excel Driver
(*.xls)};ReadOnly=1;DBQ=" & txtExlFile
    oConn.Open (txtConn)
    oRs.ActiveConnection = oConn
    oRs.CursorLocation = adUseClient
    oRs.CursorType = adOpenDynamic
    oRs.LockType = adLockReadOnly
    oRs.Open "[Comps]", , , , 2
    'oConn.Close
    'Set oRs.ActiveConnection = Nothing
    If Not oRs.EOF Or Not oRs.BOF Then
        oRs.MoveFirst
        fillform
    End If

    ' creates output file
    Set fso = CreateObject("Scripting.FileSystemObject")
    Set out =
fso.CreateTextFile("E:\Source\printcost\printcost.txt",
True, False)
```

```
    out.WriteLine ("Component, Unit, Fixed")
    out.Close


End Sub

Private Sub fillform()
'fills in text box inputs data from input file
    componentName.Text = checknull(oRs(0)) & " " &
checknull(oRs(1))
    cvrColors.Text = checknull(oRs(6))
    numClrdPages.Text = checknull(oRs(7))
    numClrsText.Text = checknull(oRs(8))
    numFold.Text = checknull(oRs(12))
    numFoldClrs.Text = checknull(oRs(13))
    numNegs.Text = checknull(oRs(10))
    numPerfPages.Text = checknull(oRs(9))
    numProofs.Text = checknull(oRs(11))
    numTotalPages.Text = checknull(oRs(2))
    fixedCost.Text = 0
    unitCost.Text = 0
    TotalCost.Text = 0

    filloptions
End Sub

Function checknull(inval As Variant) As String
    If IsNull(inval) Then
        checknull = ""
    Else
        checknull = CStr(inval)
    End If
End Function

Private Sub filloptions()
'fills in option buttons from input file
    If (LCase(oRs(3)) = "big") Then
        bigPaper.Value = True
    ElseIf (LCase(oRs(3)) = "small") Then
        smallPaper.Value = True
    End If

    If (LCase(Trim(oRs(4))) = "colored") Then
        colorCvr.Value = True
    ElseIf (LCase(Trim(oRs(4))) = "white") Then
        whiteCvr.Value = True
```

```
    ElseIf (LCase(Trim(oRs(4))) = "self") Then
        selfCvr.Value = True
    End If

    If (LCase(Trim(oRs(5))) = "perfect") Then
        perfectBind.Value = True
    ElseIf (LCase(Trim(oRs(5))) = "saddle") Then
        saddleBind.Value = True
    ElseIf (LCase(oRs(5)) = "side") Then
        sideBind.Value = True
    ElseIf (LCase(Trim(oRs(5))) = "loose") Then
        looseBind.Value = True
    End If

    If (LCase(Trim(oRs(14))) = "front") Then
        frontPrint.Value = True
    ElseIf (LCase(Trim(oRs(14))) = "front and back") Then
        twoSidePrint.Value = True
    ElseIf (LCase(Trim(oRs(14))) = "n/a") Then
        noFold.Value = True
    End If

End Sub
```

APPENDIX C. VOLUME REGRESSION

Regression on height of component as a fucntion of the number of pages.

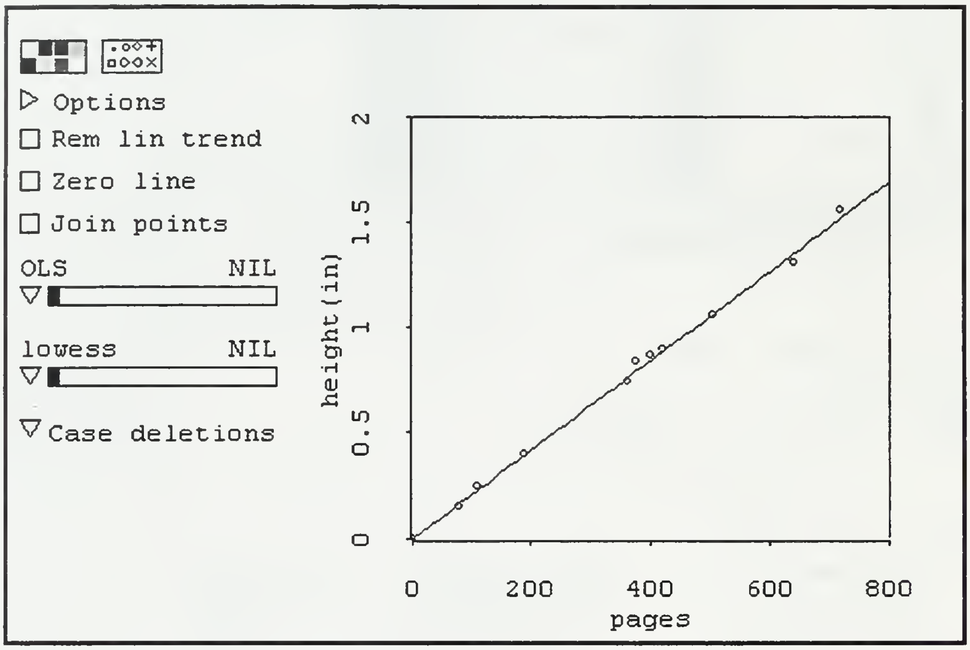
Number of pages	Observed (inches)	Regression (inches)
0	0	0
80	0.15625	0.169679
110	0.25	0.233309
190	0.40625	0.402988
364	0.75	0.77204
378	0.84375	0.801734
400	0.875	0.848396
422	0.90625	0.895058
504	1.0625	1.068979
642	1.3125	1.361676
720	1.5625	1.527113

Regression data table

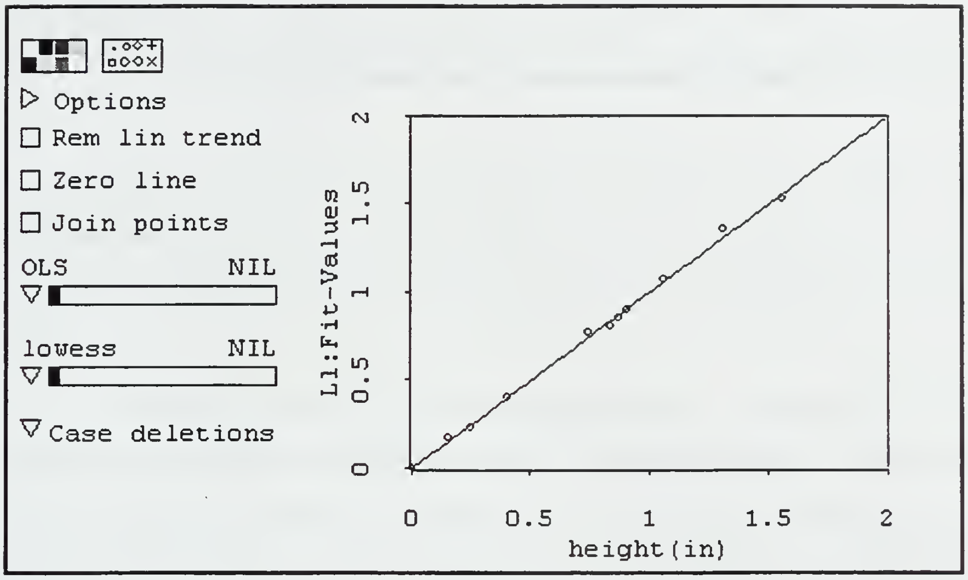
```
Data set = testData, Name of Fit = L1
Normal Regression
Kernel mean function = Identity
Response       = height(in)
Terms          = (pages)
Coefficient Estimates
Label       Estimate        Std. Error    t-value
Constant    0.00400361      0.0157775       0.254
pages       0.00212099      0.0000384448   55.170

R Squared:                0.997052
Sigma hat:                0.0280673
Number of cases:               11
Degrees of freedom:             9

Summary Analysis of Variance Table
Source       df       SS             MS              F    p-value
Regression    1    2.39774       2.39774       3043.69    0.0000
Residual      9   0.00708996     0.000787774
```

The number of pages and observed height in inches were hand calculated using a ruler to measure the height with an accuracy of 1/32 of an inch. The data points were several components from the 8800 course and two other government printed texts. The regression column is calculated by multiplying the number of pages by the pages

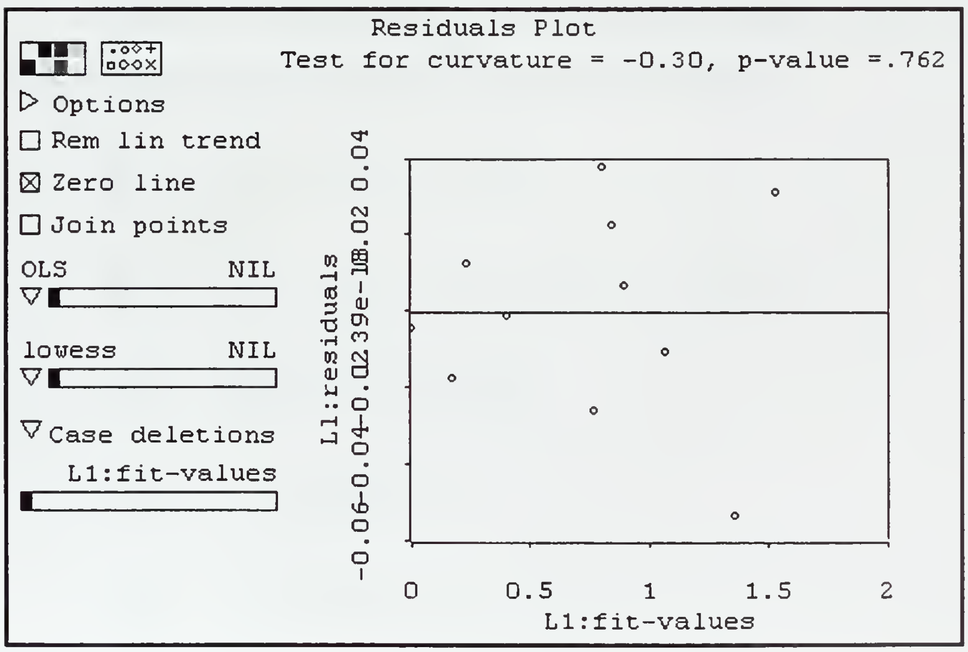
coefficient estimate, or slope (0.00212099). With an R^2 of 0.997 this regression does a very good job of capturing the behavior of the data. The constant, or intercept, is close to zero and has a very low t-value and is therefor assumed to be zero (as expected from first principals, a stack of zero pages has no height). The slope coefficient has a very large t-value which indicates that the value can not be zero.



The above graph shows observed height as a function of the number of pages. The superimposed line is the height calculated using regression slope coefficient times the number of pages. As is clearly evident the calculated line closely resembles the observed data.



This graph shows the regression fit values vs. the observed values. If the two matched perfectly they would form the line y = x, this line is superimposed to illustrate how closely the fit and observed values match.



The plot of residuals above should be randomly scattered about zero if the regression is a close approximation of the actual data. As can be seen above the residual

plot is scattered about zero and appears to have no pattern. The p-value of 0.762 indicates that there is strong evidence that the linear model is appropriate.

APPENDIX D. PROOF OF CONVEXITY

In order to assert that the model formulated above returns a globally optimal solution we must prove that the objective function is convex over a convex set of constraints. First we will direct our attention to proving that the objective function is convex.

To prove convexity of the objective function we must prove that the second derivative (or Hessian) matrix is positive semi-definite (PSD) or positive definite (PD). The first step is to take the partial derivatives with respect to the decision variables Q and Z and then the second partials thus forming the Hessian matrix. Once the Hessian has been determined we have to prove that the Hessian is PSD. This is done by showing that the diagonal elements and the determinate are positive or equal to zero (if these elements are strictly greater than zero the matrix is PD).

$$f(Q, Z) \;=\; \sigma[\varphi(Z) - Z(1 - \Phi(Z))]\left(\frac{R}{Q}\right)$$

Where $\varphi(Z)$ is the standard normal Probability Density Function (PDF), and $\Phi(Z)$ is the standard normal Cumulative Density Function (CDF).

$$\frac{\delta f}{\delta Q} \;=\; \left(\frac{-R}{Q^2}\right)\sigma[\varphi(Z) - Z(1 - \Phi(Z))]$$

$$\frac{\delta f}{\delta Z} \;=\; \left(\frac{\sigma R}{Q}\right)(-Z\varphi(Z) - 1 + Z\varphi(Z) + \Phi(Z)) \;=\; \left(\frac{\sigma R}{Q}\right)(\Phi(Z) - 1)$$

$$\frac{\delta^2 f}{\delta Q^2} \;=\; \left(\frac{2\sigma R}{Q^3}\right)(\varphi(Z) - Z(1 - \Phi(Z)))$$

$$\frac{\delta^2 f}{\delta Q \delta Z} \;=\; \left(\frac{-\sigma R}{Q^2}\right)(\Phi(Z) - 1)$$

$$\frac{\delta^2 f}{\delta Z \delta Q} \;=\; \left(\frac{-\sigma R}{Q^2}\right)(\Phi(Z) - 1)$$

$$\frac{\delta^2 f}{\delta Z^2} \;=\; \left(\frac{\sigma R}{Q}\right)(\varphi(Z))$$

The resulting Hessian Matrix is

$$H = \begin{bmatrix} \frac{\delta^2 f}{\delta Q^2} & \frac{\delta^2 f}{\delta Q \delta Z} \\ \frac{\delta^2 f}{\delta Z \delta Q} & \frac{\delta^2 f}{\delta Z^2} \end{bmatrix} = \begin{bmatrix} \left(\frac{2\sigma R}{Q^3}\right)(\varphi(Z) - Z(1-\Phi(Z))) & \left(\frac{-\sigma R}{Q^2}\right)(\Phi(Z) - 1) \\ \left(\frac{-\sigma R}{Q^2}\right)(\Phi(Z) - 1) & \left(\frac{\sigma R}{Q}\right)(\varphi(Z)) \end{bmatrix}$$

$$\text{Determinate H} = \frac{\sigma^2 R^2}{Q^4} \left(2\varphi(Z)[\varphi(Z) - Z(1-\Phi(Z))] - (\Phi(Z)-1)^2 \right)$$

Proof of convexity:

Need to show that the diagonal terms and determinate of the Hessian Matrix are positive for all values of Q and Z. We can set aside all coefficients of the form $\frac{\sigma R}{Q}$ as the second derivative is $\frac{2\sigma R}{Q^3}$, which is positive for all Q > 0. We must now prove that all terms are positive with respect to Z.

1. **Proof 1**

$$\frac{\delta^2 f}{\delta Z^2} = \left(\frac{\sigma R}{Q}\right)(\varphi(Z)) \geq 0, \quad \forall Z \geq 0$$

$\varphi(Z)$ is the Probability Density Function of the Standard Normal Distribution and is by definition greater than zero.

2. **Proof 2**

$$\frac{\delta^2 f}{\delta Q^2} = \left(\frac{2\sigma R}{Q^3}\right)(\varphi(Z) - Z(1-\Phi(Z))) \geq 0, \quad \forall Z \geq 0$$

As noted above the coefficient with respect to Q is positive for positive values of Q. Therefore must prove that the term $\varphi(Z) - Z(1-\Phi(Z))$ is positive with respect to Z.

First show that $f(Z) = \varphi(Z) - Z(1-\Phi(Z)) > 0$ at Z = 0.

$$f(0) = \frac{1}{\sqrt{2\pi}} - 0[(1-.5)-(.5-1)] = \frac{1}{\sqrt{2\pi}} > 0.$$

Now must show that $f'(Z) \leq 0, \quad \forall Z \geq 0$.

$$f'(Z) = -Z\varphi(Z) - [1-\Phi(Z)] + Z\varphi(Z)$$

$$= -[1-\Phi(Z)] < 0, \quad Z \geq 0 \quad \Rightarrow \quad f(Z) \text{ is a decreasing function of Z.}$$

Now must show that $\lim_{Z\to\infty} f(Z) = 0$.

$$\lim_{Z\to\infty} f(Z) = \lim_{Z\to\infty} [\varphi(Z) - Z(1-\Phi(z))]$$

$= \lim_{Z\to\infty} Z(1-\Phi(Z))$ which is in the form ∞*0. Using L'Hopital's Rule

$$\lim_{Z\to\infty} Z(1-\Phi(Z)) \quad = \quad \lim_{Z\to\infty} \frac{(1-\Phi(Z))}{\frac{1}{Z}} \quad = \quad \lim_{Z\to\infty} \frac{-\varphi(Z)}{\frac{-1}{Z^2}}$$

$= \lim_{Z\to\infty} Z^2\varphi(Z)$ which is still of the form ∞*0. Using L'Hopital's Rule

$$\lim_{Z\to\infty} Z^2\varphi(Z) = \lim_{Z\to\infty} \frac{Z^2}{[\varphi(Z)]^{-1}} = \lim_{Z\to\infty} \frac{2Z}{\frac{-Z\varphi(Z)}{[\varphi(Z)]^2}} = \lim_{Z\to\infty} -2\varphi(Z) = 0.$$

Therefore since $f(0) = \frac{1}{\sqrt{2\pi}} > 0$, $f'(Z) < 0$, (i.e. f(Z) is decreasing) and $\lim_{Z\to\infty} f(Z) = 0$ it must be true that $f(Z) > 0, \quad \forall\, Z \geq 0.$.

3. Proof 3

Determinate H = $\frac{\sigma^2 R^2}{Q^4} \left(2\varphi(Z)[\varphi(Z) - Z(1-\Phi(Z))] - [\Phi(Z)-1]^2\right) \geq 0, \quad \forall\, Q, Z \geq 0$.

As stated earlier we know that the Determinate is positive with respect to Q > 0, $\frac{\sigma^2 R^2}{Q^4} > 0, \forall\, Q > 0$. We are now left with having to prove the Determinate is positive with respect to Z.

Prove: $f(Z) = 2\varphi(Z)[\varphi(Z) - Z(1-\Phi(Z))] - (\Phi(Z)-1)^2 \geq 0, \quad \forall\, Z \geq 0$.

This proof will follow the same form as Proof 2, show that $f(0) > 0$, $f'(Z) \leq 0$ and that $\lim_{Z\to\infty} f(Z) = 0$.

a. Show that $f(0) > 0$.

$$f(0)=\frac{2}{\sqrt{2\pi}}\left[\frac{1}{\sqrt{2\pi}}-0(1-0.5)\right]-[0.5-1]^2=\frac{1}{\pi}-0.25= \quad 0.0683 \quad > \quad 0.$$

b. Show that $f'(Z)\leq 0$.

$$f'(Z)=-2Z\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))]+2\varphi(Z)[-Z\varphi(Z)-(1-\Phi(Z))+Z(\varphi(Z))]-2\varphi(Z)[\Phi(Z)-1]$$

$$= -2Z\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))]+2\varphi(Z)[\ (\Phi(Z)-1)]-2\varphi(Z)[\Phi(Z)-1]$$

$$= -2Z\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))]$$

Therefore we need to show that $f'(Z)=-2Z\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))] \ \leq \ 0$

Since Z and $\varphi(Z)$ are both by definition positive then the leading term $-2Z\,\varphi(Z) \ \leq \ 0, \ \ \forall Z\geq 0.$

Now we must show that the remaining term $\varphi(Z)-Z(1-\Phi(Z)) \ \geq \ 0, \ \ \forall Z\geq 0,$ which was previously proved in Proof 2.

c. Show that $\lim_{Z\to\infty} f(Z)=0.$

$$\lim_{Z\to\infty} = 2\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))]-[\Phi(Z)-1]^2$$

$$= \lim_{Z\to\infty} 2\varphi(Z)[\varphi(Z)-Z(1-\Phi(Z))] \ - \ \lim_{Z\to\infty}(\Phi(Z)-1)^2$$

$$= \lim_{Z\to\infty} 2[\varphi(Z)]^2 \ - \ \lim_{Z\to\infty} 2Z\varphi(Z)(1-\Phi(Z)) \ - \ \lim_{Z\to\infty}(\Phi(Z)-1)^2$$

$$= \lim_{Z\to\infty} 2[\varphi(Z_c)]^2 \ - \ \lim_{Z\to\infty} 2Z\varphi(Z) \ + \ \lim_{Z\to\infty} 2Z\varphi(Z)\Phi(Z_c) \ - \ \lim_{Z\to\infty}(\Phi(Z_c)-1)^2$$

$$= \ 0 \ - \ \infty * 0 \ + \ \infty * 0 \ - \ 0$$

We must now use L'Hopital's Rule on the second and third terms.

2nd term: $\lim_{Z\to\infty} 2Z\varphi(Z)=\lim_{Z\to\infty}\frac{2Z}{\varphi(Z)^{-1}}=\lim_{Z\to\infty}\frac{2}{\frac{-Z\varphi(Z)}{\varphi(Z)^2}}=\lim_{Z\to\infty}\frac{-2\varphi(Z)}{Z}=\frac{0}{\infty}=0.$

3rd term:

$$\lim_{Z\to\infty} 2Z\varphi(Z)\Phi(Z)=\lim_{Z\to\infty}\frac{2Z\Phi(Z)}{\varphi(Z)^{-1}}=\lim_{Z\to\infty}\frac{2Z\varphi(Z)+2\Phi(Z)}{\frac{-Z\varphi(Z)}{\varphi(Z)^2}}=\lim_{Z\to\infty}\left[-2\varphi(Z)^2-\frac{2\varphi(Z)\Phi(Z)}{Z}\right]=0-\frac{0}{\infty}=0.$$

$$\Rightarrow \ \lim_{Z\to\infty} f(Z)=0.$$

Having now shown that $f(0) > 0$, $f'(Z) < 0$, and $\lim_{Z \to \infty} f(Z) = 0$ we have proved that the Determinant of the Hessian matrix is positive.

4. Proof 4

Show that the constraints form a convex set. All constraints must be linear, half-spaces or convex in order to form a convex set.

Constraint 2: prove $\sum_c Fix_c\left(\frac{R_c}{Q_c}\right) + Unit_c R_c \leq Budget$ is convex.

Show that $\frac{d^2}{d^2 Q} \geq 0, \quad \forall Q.$

$$\frac{d}{dQ} = Fix\left(\frac{-R}{Q^2}\right)$$

$$\frac{d^2}{d^2 Q} = Fix\left(\frac{2R}{Q^3}\right) > 0, \quad \forall Q \text{ is therefor convex.}$$

Constraints 3 and 4 are linear.

Constraint 5: prove $SO = \sigma(\varphi(Z) - Z(1 - \Phi(Z)))$ is convex.

Show that $\frac{d^2}{d^2 Z} \geq 0 \quad \forall Z \geq 0.$

$$\frac{d}{dZ} = \sigma[\Phi(Z) - 1]$$

$$\frac{d^2}{d^2 Z} = \sigma * \varphi(Z) > 0, \quad \forall Z \text{ is therefor convex.}$$

Constraints 6 through 10 define half-spaces.

Now combining the results of Proofs 1 through 4 we can assert that $f(Q, Z)$ is strictly convex over a convex set for positive values of Q and Z, and thus assuring us that the formulation result will be a globally optimal solution.

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APPENDIX E. MCI INVENTORY POLICY ALGORITHM

```
check = 0;
LOOP(c,
  B.up(c) = mbar(c) + 3*sigma(c);
  B.lo(c) = mbar(c);
);

LOOP(c,
  Q.up(c) = min(r(c),10000);
  Q.lo(c) = min(r(c)/4, Q.up(c));
);

LOOP(c,
  B.l(c) = min(B.up(c), max(B.lo(c),1.5*mbar(c)));
  Q.l(c) = min(Q.up(c), max(Q.lo(c),3*mbar(c)));
);

move = 1;
WHILE(check lt 1 and move gt 0,
  move = 0;
  TmpBdgt = sum(c, fix(c)*(r(c)/Q.l(c)) + unit(c)*r(c));

  IF(TmpBdgt gt BDGT,
    LOOP(c,
      IF(Q.l(c) < Q.up(c),
        Q.l(c) = min(Q.l(c)*1.1,Q.up(c));
        move = 1;
      );
    );
  ELSE
    check = check + 1;
  );
);

check = 0.0;
move = 1;

WHILE(check lt 1 and move gt 0,
  move = 0;
  TmpVol = sum(c, vol(c)*(B.l(c) - mbar(c) + Q.l(c)));

  IF(TmpVol gt VOLCAP,
```

```
    LOOP(c,
      IF(B.l(c) gt B.lo(c),
        B.l(c) = max(B.l(c)*0.9,B.lo(c));
        move = 1;
      );
    );
  ELSE
    check = check + 1;
  );
);
```

APPENDIX F. OPTIMAL HEURISTIC ALGORITHM

The heuristic algorithm described in Chapter 4 provides the same solution as the non-linear programming model, yet is much easier to implement. Instructions on how this can be programmed into a database or spreadsheet follow.

1) Determine the mean monthly demand and standard deviation of each component.

2) Since the order lead-time is about two months, multiply mean monthly demand by two to get the mean lead-time demand and multiply the standard deviation of monthly demand by the square root of two to get the standard deviation of lead-time demand.

3) Reorder points should be set equal to lead-time demand plus three times the standard deviation of lead-time demand.

4) Reorder quantities should be large. Set the reorder quantities upper limits at the lesser of one year's demand or 10,000. The artificial limit of one year's demand is discussed in section III.B above. An upper bound of 10,000 was used because of limits placed on order quantity in the 1999 print contract. Use the smaller of the two numbers.

```
check = 0;
LOOP(c,
  B.up(c)=mbar(c)+3*sigma(c) ;          'set upper bound on reorder point
  B.lo(c)=mbar(c) ;                     'set lower bound on reorder point
 );
 LOOP(c,
  Q.up(c) = min(r(c),10000) ;           'set upper bound on reorder quantity
  Q.lo(c) = min(r(c)/4,Q.up(c)) ;       'set lower bound on reorder quantity
 );

LOOP(c,                         'sets initial variable values for each component
  B.l(c) = 3.0*sigma(c) + mbar(c);
  Q.l(c) = min(max(r(c),Q.lo(c)),Q.up(c));
);

check = 0;
move=1;                                 'checks for feasibility of budget constraint
WHILE(check lt 1 and move gt 0,
  move=0;
  TmpBdgt = sum(c, fix(c)*(r(c)/Q.l(c)) + unit(c)*r(c));
  IF(TmpBdgt gt BDGT,
    LOOP(c,
      IF( Q.l(c) lt Q.up(c),
```

```
            Q.l(c) = min(Q.l(c)*1.1,Q.up(c));
            move=1;
         );
      );
   ELSE
      check = check + 1;
   );
);

check = 0;
move=1 ;
WHILE(check lt 1 and move gt 0,      'checks for feasibility of capacity constraint
   move=0 ;
   TmpVol = sum(c, vol(c)*(B.l(c) - mbar(c) + Q.l(c)));
   IF(TmpVol gt VOLCAP,
      LOOP(c,
         IF( B.l(c) gt B.lo(c),
            B.l(c) = max(B.l(c)*0.9,B.lo(c));
            move=1;
         );
      );
   ELSE
      check = check + 1;
   );
);
```

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